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Uranium Releases from the Oak Ridge Reservation– a Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures

Submitted to the Tennessee Department of Health by

ChemRisk
A Service of McLaren/Hart

OAK RIDGE HEALTH STUDIES
OAK RIDGE DOSE RECONSTRUCTION

– TASK 6 REPORT –

URANIUM RELEASES FROM THE OAK RIDGE RESERVATION– A REVIEW OF THE QUALITY OF HISTORICAL EFFLUENT MONITORING DATA AND A SCREENING EVALUATION OF POTENTIAL OFF-SITE EXPOSURES

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GLOSSARY

absorbed dose - a measurement of the energy imparted by radiation to a unit mass of material, such as tissue in the body. Absorbed dose is quantified by the *gray* (Gy) which is equal to the absorption of one joule of energy in one kg mass of tissue. Formerly, absorbed dose was quantified in terms of the *rad* (Radiation Absorbed Dose): 1 gray (Gy) = 100 rad.

actinon - a short-lived naturally occurring radioactive gas (also known as radon-219) that is generated by the radioactive decay of uranium-235.

alpha buildings - collection of five Y-12 buildings which housed the first stages of the electromagnetic enrichment process.

air sampling - the collection and analysis of a measured quantity of air from a defined area or source. Samples of air are collected to measure or to detect the presence of radioactive substances, particulate matter, or chemical pollutants. Samples can be taken from rooms, exhaust systems, stacks, or ambient air.

alpha particle - a positively charged particle that is ejected spontaneously from the nuclei during the decay of certain radioactive elements such as uranium. Physically, it is identical to a helium nucleus, with two neutrons and two protons, and has a mass number of 4 and an electrostatic charge of +2. Generally, alpha particles have very low-penetrating power; even the most energetic alpha particle will fail to penetrate the skin. Alpha-emitting isotopes only pose a health hazard if directly introduced into the body either by inhalation or ingestion.

AMAD - (Activity Median Aerodynamic Diameter) given in microns, is a measure of the diameter of a particle size as it relates to inhalation.

anisokinetic sampling - nonrepresentative sampling of an air or fluid stream caused by a difference between the air or fluid velocity in the sampling probe and the velocity of the particles in the stack. Such sampling inaccuracies can be a source of bias in effluent sampling. In contrast, isokinetic sampling, in which the two velocities are equal can result in an unbiased sample of the stack effluent.

Atomic Energy Commission (AEC) - a federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian application. Abolished by the Energy Reorganization Act of 1974 and succeeded by the Energy Research and Development Administration. The former AEC and ERDA (1974 - 1977) was split in 1977 between the Nuclear Regulatory Commission and the Department of Energy.

background radiation - the radiation received by man from natural and environmental sources including cosmic rays, radiation from the naturally radioactive elements in the environment, and natural concentrations of radionuclides in the body (carbon-14, potassium-40). The usually quoted average individual exposure from background radiation for a person living in the continental United States is 250 to 300 millirem per year.

beta buildings - three Y-12 buildings which housed the second stages of the electromagnetic enrichment process.

bias - a systematic error of measurements that results in either an over- or underestimation of the result. Bias is not the same as accuracy, which is a measure of how close a value is to the true number. Precision is a measure of the repeatability of a measurement.

biokinetic modeling - the use of mathematical models to quantify the movement and accumulation of ingested or inhaled material throughout the human body.

calibration - the check or correction of the accuracy of a measuring instrument to assure proper operational characteristics. Calibration of measuring equipment is performed periodically to ensure an accurate response of the detector system to the properties it is measuring.

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calutrons - production scale mass spectrometers that were used at Y-12. The high magnetic fields were used to electromagnetically separate the lighter U-235 isotope from the heavier, more naturally-abundant U-238 isotope. Derived from California University Cyclotron.

cascade - a system of gaseous diffusion process components arranged so as to enrich uranium in its U-235 component. Porous gaseous diffusion barrier was contained in stages, the basic units of the enrichment process. Because each stage provided only about 0.2% enrichment, a number of stages were connected together to form cells, and a large number of cells were connected in series to provide the needed enrichment. The system of cells was called a cascade because about half the introduced gas flowed to the next higher stage, while the remaining portion flowed to the next lower stage.

chemical symbols - abbreviations for different elements and compounds. Examples of elements include U for uranium, O for oxygen, N for nitrogen, and F for fluorine. Examples of compounds include UF_4 for uranium tetrafluoride (green salt) and UO_3 for uranium trioxide (orange oxide).

counter - a general designation usually applied to radiation detection instruments or radiation survey meters that detect and measure each individual interaction of a particle or gamma ray with the materials in the detector portion of the instrument. The signal registered by these instruments represents an ionization event and can be referred to as a count; examples of counters include the Geiger-Mueller (G-M) counter.

curie (Ci) - a unit used to quantify the amount of radioactivity associated with a radioactive element. The curie is equal to 37 billion disintegrations per second, which is exactly the rate of decay of one gram of radium-226. A curie (Ci) is also the quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second. Named for Marie and Pierre Curie, who discovered radium in 1898. The S.I. unit for activity is the Becquerel (Bq); one curie is equal to 37 billion Bq.

depleted uranium - on the ORR, depleted uranium consisted mostly of U-238 and usually contains between 0.14 and 0.20% uranium-235 by weight. Natural uranium contains 0.72% uranium-235, while enriched uranium contains greater than 0.72% uranium-235 by weight. For example, depleted uranium is generated as a result of the K-25 gaseous diffusion uranium enrichment and is found in the tailings portion of the process outputs.

detector - a material or device that is sensitive to radiation and which can produce a response signal suitable for measurement or analysis. It is this response that can be converted into a characteristic that can be counted or measured as in a radiation detection instrument.

DOE - the U.S. Department of Energy.

dose - the total amount of ionizing radiation or chemical agent received by an person. For radiation, this differs from absorbed dose which represents the total energy deposited in a unit mass of tissue. There are specific definitions of radiation dose which are described by technical terminology such as absorbed dose, equivalent dose, and effective dose.

effective dose - The sum over specified body tissues of the products of the equivalent dose in that tissue and the weighting factor for that tissue. These weighting factors reflect that some organs are more susceptible to radiation damage than others, and have a greater risk of producing cancer or other adverse effects. Each weighting factor represents the relative contribution of the specified organ or tissue to the total risk of effects such as cancer, compared to that from uniform irradiation of the whole body. The unit of effective dose is the rem (traditional system) or sievert (SI system); 1 sievert (Sv) = 100 rem.

effluent - treated or untreated air emission or liquid discharge containing contaminants that has been released into the environment from a facility.

enriched uranium - on the ORR, enriched uranium typically contained between 0.95% and $99% uranium-235. Natural uranium contains 0.72% uranium-235, while depleted uranium contains less than 0.72% uranium-235.

GLOSSARY

enrichment of uranium - a process in which the relative abundance of one of the isotopes of uranium is increased with respect to the others. These processes in the past used the difference in the mass of the isotopes to increase the relative fraction of one isotope over the others. The resultant material is enriched in one particular isotope (usually uranium-235) and depleted in its other isotope (uranium-238).

episodic releases - nonroutine or accidental releases of relatively short duration.

equivalent dose - the relative biological impact of each type of radiation (alpha, beta, or gamma) upon cells differs due to the relative behavior of that radiation. To account for each type of radiation, the absorbed dose is multiplied by a quality factor for that particular type of radiation (see quality factor). The quality factor for a particle depends also on its energy. This quality factor adjusts for the relative biological impact of each type of radiation, and the product of the absorbed dose and the quality factor is referred to as the equivalent dose. Any combination of different types of radiation can be summed using the equivalent doses. The unit of equivalent dose is the rem (traditional system) or sievert (SI system); 1 sievert (Sv) = 100 rem.

exposure point - a location where people may come into contact with contaminants in environmental media such as air, soil, water, and food also called a reference location.

exposure routes - mechanisms or pathways through which contaminants in environmental media (*e.g.*, air, soil, or water) may affect an individual. Some commonly encountered exposure routes are: inhalation of contaminated air, ingestion of contaminated soil, water, and food stuffs, and dermal contact of contaminated soil or water.

external exposure pathways - exposure routes arising from close proximity to radioactive material that is not taken into the body. Examples of external exposure are immersion in contaminated air or water and exposures from contaminants in or on the ground. Through these pathways, beta and gamma emitting radionuclides can impart a radiation dose to a nearby person without entering the body of the person. Also see immersion.

femtocurie - one thousandth of a millionth of a millionth of a curie, 1×10^{-15} Ci (see curie). One femtocurie is one thousandths of a picocurie (see picocurie).

gaseous diffusion enrichment - a process by which uranium hexafluoride is passed through a series of semipermeable molecular barriers for the purpose of separating the lighter uranium-235 isotope from the heavier, more naturally-abundant uranium-238 isotope (see enrichment of uranium).

gastrointestinal tract (GI) - the digestive tract, which is composed of four compartments: the stomach, small intestine, and upper and lower large intestines.

gray - a unit, in the International System of Units (SI), of absorbed dose that is equal to 1 joule per kilogram (see absorbed dose).

green salt - the common name for uranium tetrafluoride (UF_4); this product was used in Buildings 9212 and 9206 at Y-12.

gross or net alpha radioactivity - radioactivity measured in terms of alpha particles emitted, with no determination of their energy or the identity of the specific radionuclides from which they were emitted.

health impacts - deleterious health effects. For uranium, the potential effect from its emitted radiation is cancer. Chemical toxicity effects of uranium may lead to kidney damage.

health physics - the profession concerned with recognition, evaluation, and control of health hazards associated with ionizing and nonionizing radiation.

ICRP - the International Commission on Radiological Protection.

GLOSSARY

immersion - in this report, the surrounding of an individual by an atmosphere or body of water contaminated with radionuclides that emit gamma or beta radiation.

ionization chamber - an instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of electricity. (See counter.)

isotopes - atoms with the same number of protons, but different numbers of neutrons in their nuclei. Carbon -12, carbon-13 and carbon-14 are isotopes of the element carbon, the numbers denoting the approximate atomic weights. Isotopes have very nearly the same chemical properties, but often different physical properties, *e.g.*, carbon-12 and carbon-13 nuclei are stable, carbon-14 is radioactive.

kilo - a prefix that multiplies a basic unit by 1000. For example, 1 kilogram = 1000 grams.

LOAEL - (Lowest-Observed-Adverse-Effect Level). In dose-response experiments, the lowest exposure level at which there are statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control group.

mass loading - the concentration of dust or particulates in air: usually quantified as grams of dust in a cubic meter of air ($g\ m^{-3}$). This value can be used to quantify the concentration of a contaminant in air as a result of dust resuspension if the concentration of the contaminant in the surface layer of the soil is known. Mass loading values can be used in conjunction with breathing rates to determine the quantity of a resuspended contaminant that is inhaled.

microcurie - one-millionth of a curie, 1×10^{-6}. (See curie.)

micron - one-millionth of a meter, 1×10^{-6} m.

millirem - one-thousandth of a rem, 1×10^{-3} rem.

natural uranium - natural or "normal" uranium contains 0.72% uranium-235. Contrast with enriched uranium, which contains more than the natural concentration of uranium-235, and depleted uranium, which contains less than 0.72% uranium-235.

NCRP - the National Council on Radiation Protection and Measurements. The Council strives to provide accurate, complete, and useful information for the advancement of the field of radiation protection.

NOAEL - (No-Adverse-Effect-Effect-Level). In dose-response experiments, an exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered to be adverse, nor precursors to specific adverse effects.

oralloy - uranium enriched in the isotope uranium-235. This is a Manhattan Project nickname, from Oak Ridge Alloy.

orange oxide - the common name for uranium trioxide (UO_3); this product was used in Buildings 9212 and 9206 at Y-12.

ORR - the Oak Ridge Reservation.

parts per million (ppm) - parts of a substance contained in a million parts of air (or water) by volume.

percentiles - if a large set of data is arranged from its smallest value to its largest, and this list is divided into 100 classes containing nearly equal numbers of data, then each percentile represents the highest value within that class. Thus 5% of the data are less than or equal to the 5th percentile, and approximately 95% of the data are greater than or equal to the 5th percentile. The median is defined as the 50th percentile, which divides the data (approximately) into halves.

GLOSSARY

picocurie - one millionth of a millionth of a curie, 1 x 10^{-12} Ci (see curie). One disintegration per second of a radioactive element equals about 27 pCi.

proportional counter - an instrument in which an electronic detection system receives pulses that are proportional to the number of ions formed in a gas-filled tube by ionizing radiation. Used to measure alpha and beta activity on air, soil, and water samples.

purge cascade - a segment of the gaseous diffusion process equipment that was used to separate and remove light gases (such as air, fluorine, and coolant vapors) from the uranium hexafluoride that was being enriched. If these light gases were not removed, they would accumulate at the top of the cascade and block the flow of enriched uranium hexafluoride.

quality factor - the factor by which the absorbed dose is to be multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiations, the biological damage to exposed persons per unit of energy absorbed in the body. It is used because some types of radiation, such as alpha particles, are more biologically damaging than other types.

radioactive decay - the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope.

radionuclide - an unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

radon - a short-lived naturally occurring radioactive gas (radon-222) that is generated by the radioactive decay of uranium-238.

rem - acronym of roentgen equivalent man. The unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary X-rays. (See equivalent dose, effective dose, quality factor.)

reference dose - a criterion recommended by the USEPA to evaluate chronic noncarcinogenic health effects of a chemical. It is the highest dose of a chemical that is not expected to cause adverse health effects over a lifetime of daily exposure.

reference location - a geographic location of individuals within the assessment domain where concentrations are calculated by a model.

Reservation - for purposes of this report, used to refer to the Oak Ridge Reservation.

risk - the probability of a deleterious health effect, such as cancer, being induced.

scintillation counter - the combination of phosphor, photomultiplier tube, and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation. (See counter.)

soil resuspension - the transport of soil particles from the ground surface to the air by the action of mechanical disturbance or wind.

source term - the quantity, chemical and physical form, and the time history of contaminants released to the environment from a facility.

thoron - older name of a short-lived naturally occurring radioactive gas (radon-220) generated by the radioactive decay of thorium-232.

tuballoy - a commonly used synonym for depleted uranium. Likely derived from Tube Alloys, the cover name for the British Atomic Energy Office.

GLOSSARY

UCl_4 - uranium tetrachloride, used at Y-12 for electromagnetic enrichment during the Manhattan Project.

UF_4 - uranium tetrafluoride, or green salt, was processed at both Y-12 and K-25.

UF_6 - uranium hexafluoride or "hex," was in K-25 enrichment operations and received at Y-12 for weapons production.

UO_2 - uranium dioxide.

UO_3 - uranium trioxide, often called orange oxide, was used at Y-12.

U_3O_8 - uranium oxide, the most common oxide of uranium found in typical ores. U_3O_8 is extracted from the ore during the milling process. The ore typically contains only 0.1% U_3O_8. The yellow-cake, the product of the milling process, contains about 80% U_3O_8.

$UO_2(NO_3)_2$ - uranyl nitrate, a product encountered in the refinement of enriched uranium. These activities occurred in Buildings 9206 and 9212 at Y-12.

uncertainty - the level of confidence in a given estimate based on the quality and quantity of the available data. Inherent uncertainties are generated by a number of sources including: uncertainties in measurements, absence of data due to the lack of environmental monitoring, lack of knowledge about some physical processes and operational procedures, and the approximate nature of mathematical models used to predict the transport of released materials.

uranium - a naturally-occurring, radioactive metal which, in natural ores, has an atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7%) and uranium-238 (99.3% of natural uranium). Natural uranium also includes a very small amount of the daughter uranium-234 by weight. The activity associated with this U-234 is significant as U-235 enrichment increases. Uranium has been used chiefly in nuclear reactors and nuclear explosives.

UNITS & CONVERSIONS

METRIC MULTIPLES

Multiple	Decimal Equivalent	Prefix	Symbol
10^{6}	1,000,000	mega-	M
10^{3}	1,000	kilo-	k
10^{2}	100	hecto-	h
10	10	deka-	da
10^{-1}	0.1	deci-	d
10^{-2}	0.01	centi	c
10^{-3}	0.001	milli-	m
10^{-6}	0.000001	micro-	µ
10^{-9}	0.000000001	nano-	n
10^{-12}	0.000000000001	pico-	p
10^{-15}	0.000000000000001	femto-	f
10^{-18}	0.000000000000000001	atto-	a

METRIC CONVERSION TABLE

Multiply	by	to obtain	Multiply	by	to obtain
in.	2.54	cm	cm	0.394	in.
ft	0.305	m	m	3.28	ft
ac	0.404	ha	ha	2.47	ac
mi	1.61	km	km	0.621	mi
lb	0.4536	kg	kg	2.205	lb
liq. qt.-U.S.	0.946	1	1	1.057	liq. qt.-U.S.
ft^2	0.093	m^2	m^2	10.764	ft^2
mi^2	2.59	km^2	km^2	0.386	mi^2
ft^3	0.028	m^3	m^3	35.31	ft^3
d min^{-1}	0.450	pCi	pCi	2.22	d min^{-1}
pCi l^{-1} (water)	10^{-9}	µCi mL^{-1} (water)	µCi mL^{-1} (water)	10^{9}	pCi L^{-1} (water)
pCi m^{-3} (air)	10^{-12}	µCi cm^{-3} (air)	µCi cm^{-3} (air)	10^{12}	pCi m^{-3} (air)

TRADITIONAL AND INTERNATIONAL SYSTEMS OF RADIOLOGICAL UNITS (Traditional units are in parentheses)

Quantity	Name	Symbol	Expression in Terms of Other Units
absorbed dose	gray	Gy	1 J kg^{-1}
	(rad)	rad	10^{-2} Gy
activity	becquerel	Bq	1 d s^{-1} (disintegration per second)
	(curie)	Ci	$3.7x10^{10}$ Bq
dose equivalent	sievert	Sv	100 rem
	(rem)	rem	10^{-2} Sv
exposure	coulomb per kilogram		C kg^{-1}
	(roentgen)	R	$2.58x10^{-4}$ C kg^{-1} in air

Properties and Hazards of Uranium

Uranium is a naturally-occurring radioactive element that is used for nuclear reactor fuel and in nuclear weapon components like the ones made at Oak Ridge. When hit by thermal neutrons, uranium can achieve nuclear fission, in which the uranium-235 isotope (^{235}U) splits into fragments and releases much energy. Uranium-238 (^{238}U) can also undergo fission when hit by fast neutrons. As shown below, natural uranium is made up of three main forms, or "isotopes."

Isotope	Abundance in Natural Uranium (% wt.)	Half-Life (years)
Uranium-234	0.0057%	246,000
Uranium-235	0.72%	704 million
Uranium-238	99.28%	4.47 billion

Oak Ridge's K-25 & Y-12 Sites enriched the ^{235}U in uranium to levels from a few percent (for use in reactors) to over 90% by weight for use in nuclear powered submarines and for weapons. Enrichment was performed using electromagnetic, liquid thermal diffusion, gaseous diffusion, gas centrifuge, and laser techniques.

The three main uranium isotopes all emit alpha particles. Some gamma rays are less frequently emitted from ^{235}U. Since alpha particles can't penetrate the outer layer of our skin, the most significant radiation hazard from uranium comes when it is inhaled or ingested. The degree of hazard from uranium exposure depends on its chemical and physical form and its degree of ^{235}U enrichment. Because past enrichment processes couldn't separate ^{234}U from ^{235}U due to their small differences in mass, ^{234}U was enriched along with ^{235}U. While ^{234}U makes up only a small fraction of the weight of natural uranium, its contributes as much as half of its total radioactivity. As uranium is enriched in ^{235}U, ^{234}U rapidly becomes the major radiation source and gamma radiation from ^{235}U also increases.

As a heavy metal, uranium can also be toxic to the kidneys. At high exposures, kidney failure can result. Normal, healthy kidneys apparently can repair some damage caused by uranium poisoning. Scientists are uncertain whether these repair mechanisms are compromised by low-level, chronic exposures to uranium. Further discussions regarding the chemical and radiological toxicity of uranium are presented in Appendix M to this report.

EXECUTIVE SUMMARY

Preliminary investigations in the Oak Ridge Dose Reconstruction Feasibility Study indicated that uranium was not among the list of contaminants that warranted highest priority for detailed investigation of potential off-site health effects (ChemRisk 1993b). After reviewing the findings of the preliminary Feasibility Study evaluation of uranium releases, several individuals who had been long-term employees at Oak Ridge uranium facilities and a number of ORHASP members nonetheless recommended that past uranium emissions and potential resulting exposures receive closer examination. These recommendations were based on the following considerations:

- Available records of past uranium releases were found to be incomplete, and there was knowledge of substantial uranium releases that had gone unmonitored and unreported;
- the different isotopes of uranium had been evaluated separately in the Feasibility Study;
- the releases from the three ORR complexes (K-25, X-10, and Y-12) had been evaluated separately in the Feasibility Study; and
- there had been no direct evaluation in the Feasibility Study of the potential combined exposures that members of the public could have received as a result of concurrent releases of all of the uranium isotopes from the three ORR complexes.

When the Oak Ridge Dose Reconstruction was initiated in 1994, it included a Task 6 component that entailed further evaluation of Oak Ridge uranium operations and effluent monitoring records to determine if uranium releases from the Oak Ridge Reservation (ORR) likely resulted in off-site doses that warrant further study. This report summarizes the methods and results of that evaluation.

The Task 6 investigation followed these basic steps:

- Information that described uranium uses and releases on the ORR was collected.
- Effluent monitoring data were evaluated for quality and for consistency with previous U.S. Department of Energy (DOE) historical uranium release reports.
- Since the airborne effluent monitoring data were found to be incomplete, updated estimates of airborne uranium releases over time were generated using the more complete data available to the project team.
- Because of the nature of the available data, the screening evaluation of potential off-site exposures to waterborne uranium was based on environmental measurements of uranium in these local surface waters. Waterborne uranium releases from the Oak Ridge complexes were not routinely measured near their individual points of origin like airborne effluents were. Waterborne releases from X-10 were routinely sampled at White Oak Dam, and the uranium isotopes were among those evaluated under the Task 4 dose reconstruction for releases from White Oak Creek to the Clinch River. Early Task 4 screening indicated that the uranium isotopes were not among the eight radionuclides that warranted detailed dose reconstruction. Uranium concentrations were also periodically measured in samples of EFPC water collected just downstream of New Hope Pond on the Y-12 Site, and at the confluence of Poplar Creek and the Clinch River near the K-25 Site.

- Air dispersion models were used to estimate uranium air concentrations at selected reference locations near each ORR facility. Due to complexities of the topography surrounding the Y-12 facility, an alternate approach to classical air dispersion modeling was used to estimate uranium air concentrations for the selected reference location. For each reference location, uranium concentrations in surface water and soil were estimated from environmental measurement data.
- A screening-level evaluation of the potential for health impacts was performed by calculating uranium intakes and associated radiation doses. A two-tiered exposure assessment methodology was employed, which provided both upper bound and more typical results. These results are called screening indices. The calculated screening indices were compared to the decision guide established by the Oak Ridge Health Agreement Steering Panel to assess if releases of a material warrant detailed investigation.

Independent efforts to reconstruct estimates of past airborne uranium releases focused in most detail on the Y-12 production facility, the K-25 gaseous diffusion plant, and the S-50 liquid thermal diffusion plant. For the Y-12 Plant, releases from operations that were historically monitored were quantified by the project team based on measurements of indoor uranium concentrations and ventilation exhaust rates, or detailed stack sampling and analysis records found on archived computer tapes. For periods in which effluent sampling was not performed, or for which sampling records could not be found, air releases were estimated by the project team using averages of releases for adjacent years or using uranium production data (relative rates of production over time) to scale monitoring results from preceding or subsequent periods for which monitoring data were available. Independent release estimates for 1944 to 1988 were determined by the Task 6 project team since the bulk of the releases occurred during this period. DOE release estimates for the period 1989 through 1995 are considered significantly more reliable due to improved effluent monitoring.

As shown in Table ES-1 and Figure ES-1, the independent evaluation of past Y-12 airborne uranium releases yielded results that are over seven times higher than release totals reported by the DOE, with almost 44,000 kilograms more total uranium released than officially reported. The difference between the Task 6 and DOE estimates is largely due to DOE's use of incomplete sets of effluent monitoring data and related documents, together with their use of some annual release estimates that are based on effluent monitoring data that were not adequately corrected to account for sampling biases. The Task 6 estimates also include some unmonitored releases that were not included in official release estimates.

The independent evaluation of airborne uranium releases from the K-25/S-50 complex was based on analysis of uranium accountability records and incident reports, calculation of purge cascade[1] releases using

[1]A "cascade" is a system of gaseous diffusion process components arranged so as to enrich uranium in its U-235 component. Porous gaseous diffusion barrier was contained in stages. Because each stage provided only about 0.2% enrichment, a number of stages were connected together to form cells, and a large number of cells were connected in series to provide the needed enrichment. The system of cells was called a cascade because about half the introduced gas flowed to the next higher stage, while the remaining portion flowed to the next lower stage. The purge cascade was a segment of the process equipment that was used to separate and remove light gases (such as air, fluorine, and coolant vapors) from the uranium hexafluoride that was being enriched. If these light gases were not removed, they would accumulate at the top of the cascade and block the flow of enriched uranium hexafluoride.

monitoring data from that system, and use of results of periodic monitoring in three individual buildings on the K-25 Site. A database of over 1,200 documented uranium release events was developed using data from over 40 sources, and associated uranium losses were estimated.

Table ES-1: Airborne Uranium Release Estimates for the Y-12 Plant Prepared by the Task 6 Team and Published by DOE†

Year	Task 6 Estimate (kg)	DOE Estimate (kg)
1944	310	55
1945	670	102
1946	390	102
1947	250	55
1948	650	0
1949	650	0
1950	650	0
1951	650	0
1952	650	0
1953	4000	30
1954	3800	32
1955	3800	32
1956	3000	43
1957	2300	41
1958	5700	41
1959	6200	120
1960	930	99
1961	1300	109
1962	1400	100
1963	2100	103
1964	2700	170
1965	640	281
1966	920	212
1967	340	212
1968	440	211
1969	250	223
1970	300	259
1971	580	290
1972	870	222
1973	410	206
1974	210	207
1975	210	209
1976	210	207
1977	210	206
1978	210	205
1979	210	206
1980	220	218
1981	210	207
1982	210	207
1983	210	208
1984	330	329
1985	210	210
1986	210	211
1987	150	116
1988	150	116
1989*		44
1990*		21
1991*		21
1992*		7
1993*		3
1994*		24
1995*		2
TOTAL	50,000	6,535

* Values for these years were based on releases reported by DOE. Release estimates for these late years were not independently reconstructed by the project team.

† DOE Estimates from Lay et al. 1986 and Rogers 1985. Task 6 estimates are rounded to 2 significant figures.

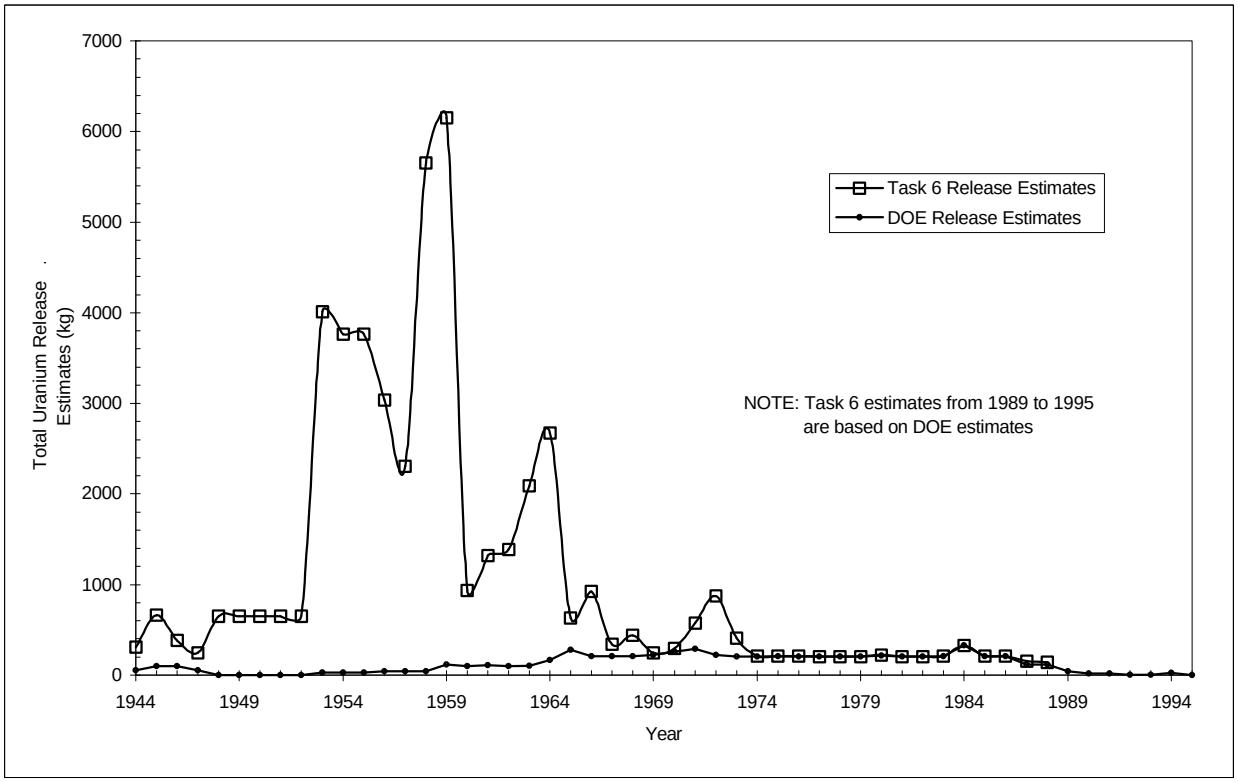


Figure ES-1: Airborne Uranium Release Estimates for the Y-12 Plant Prepared by the Task 6 Team and Published by DOE

Purge cascade releases were reconstructed by the project team for selected time periods. While they were the only airborne releases from K-25 that were historically monitored on a routine basis, purge cascade releases made up a small fraction of total uranium releases from the K-25 complex (e.g., 1.5% over 1953-1955 and 0.06% for 1975). Task 6 screening also included estimates of uranium releases from a series of UF_6 cylinder fire tests that were conducted in 1965. K-25 airborne releases after 1985 were based on data contained in annual environmental reports issued by DOE. As shown in Table ES-2 and Figure ES-2, the independent evaluation of past K-25/S-50 airborne uranium releases yielded results that are almost 5,300 kg greater than the release totals reported by the DOE.

Figure ES-3 presents the airborne release estimates generated by the Task 6 team for both complexes and those reported by the DOE for the period 1944 through 1995.

Once uranium releases had been quantified, various techniques were used to estimate air concentrations at reference locations surrounding the ORR. Air dispersion modeling was used to identify the communities surrounding the three facilities that were used for exposure assessment. Due to the considerable distances between the Y-12, K-25/S-50 and X-10 facilities, three distinct reference locations were used for the exposure assessment. The reference location for each complex was selected based on consideration of housing areas close to the facility, alignment with predominant wind directions, and habitation patterns during the periods of most significant releases.

Table ES-2: Airborne Uranium Release Estimates for the K-25/S-50 Complex Prepared by the Task 6 Team and Published by DOE†

Year	Task 6 Estimate (kg)	DOE Estimate (kg)
1944	58	0
1945	3000	0
1946	1.4	1
1947	1.0	1
1948	4.8	5
1949	80	45
1950	140	136
1951	200	146
1952	1200	345
1953	1300	1307
1954	80	68
1955	270	264
1956	260	225
1957	310	306
1958	2700	2711
1959	540	531
1960	1500	977
1961	780	773
1962	50	29
1963	1000	1005
1964	7.0	7
1965	270	269
1966	1.0	1
1967	2.0	2
1968	1.8	1
1969	10	9
1970	8.0	8
1971	50	21
1972	50	49
1973	290	144
1974	620	622
1975	370	371
1976	110	45
1977	30	17
1978	20	19
1979	50	25
1980	120	21
1981	70	5
1982	74	2
1983	2.0	2
1984	1.0	1
1985	1.2	1
1986	0.20	0
1987	0.40	0
1988	460	2
1989*		1
1990*		2
1991*		40
1992*		112
1993*		12
1994*		10
1995*		16
TOTAL	16,000	10,713

* Values for these years were based on releases reported by DOE. Release estimates for these late years were not independently reconstructed by the project team.

† DOE Estimates are from Lay et al. 1986 and Rogers 1985. Task 6 estimates are rounded to 2 significant figures.

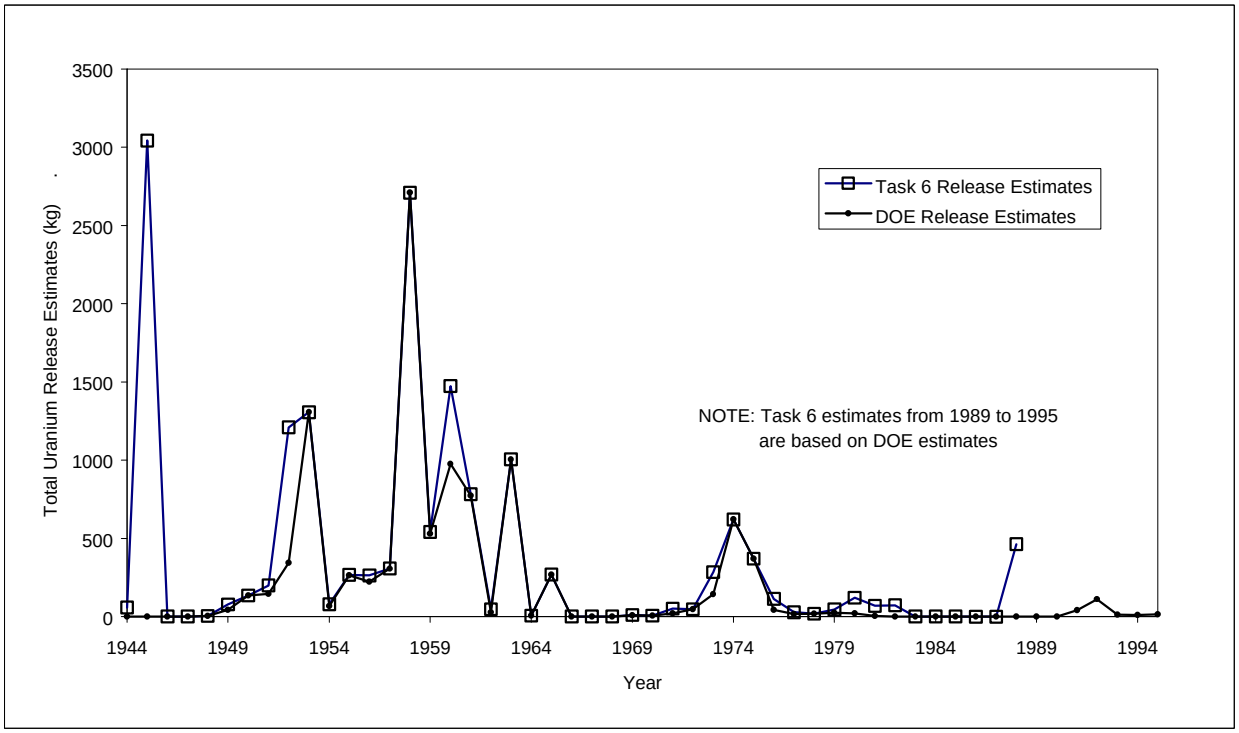


Figure ES-2: Airborne Uranium Release Estimates for the K-25/S-50 Complex Prepared by the Task 6 Team and Published by DOE

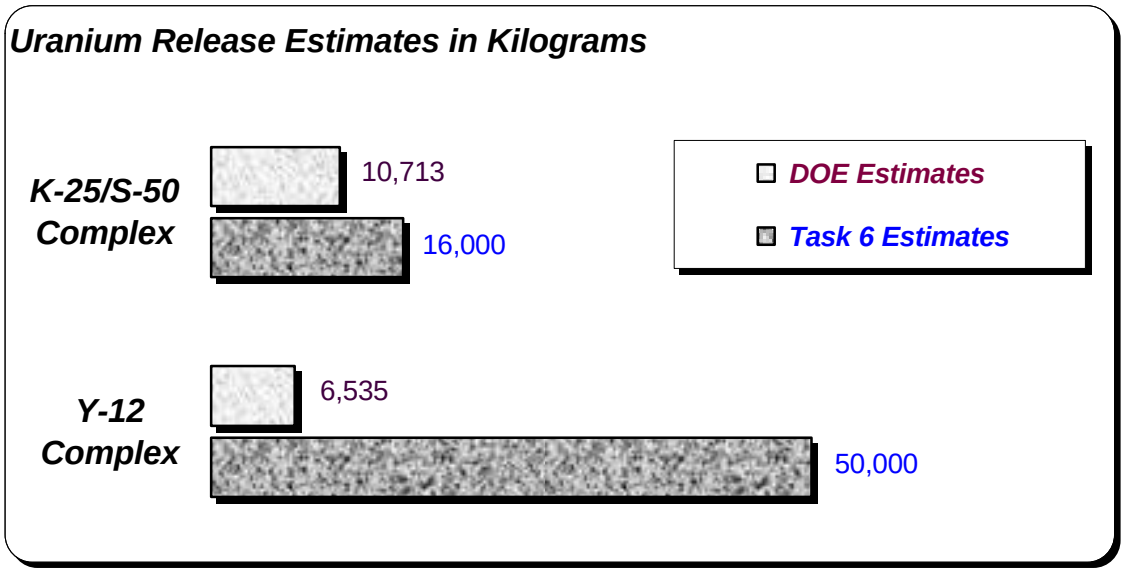


Figure ES-3: Airborne Uranium Release Estimates for Y-12 and K-25/S-50 Prepared by the Task 6 Team and Published by DOE

Three reference locations were selected for use in the Task 6 screening assessments. Initial screening of exposures at other nearby locations confirmed that these three reference locations received the largest impact from past releases from the ORR facilities.

Y-12 Reference Location - Scarboro Community

For uranium releases from the Y-12 complex, the Scarboro community was selected as the reference location. The Scarboro community is located approximately 1 km north of Y-12, and is separated from the Y-12 facility by Pine Ridge. The reference location was located at what is currently the Scarboro community center. The proximity of Scarboro to the Y-12 site suggests that screening results would present upper bound values. The closest surface water body to the Scarboro community is East Fork Poplar Creek (EFPC), which runs along the south side of the Y-12 facility, turns toward the north and northwest, and passes about 0.4 mile to the northeast of the populated area of Scarboro at its closest point.

K-25/S-50 Reference Location - Union/Lawnville

For K-25/S-50 releases, the selected reference location was the Union/Lawnville community, which is located approximately 4.5 km south-southwest of the K-25/S-50 complex. Based on the initial air dispersion modeling, as well as an assessment of areas around the K-25/S-50 facilities that were inhabited, this community was selected as a suitable reference location for the assessment. The location of the community is defined by the Union Church, which is located on Lawnville Road, approximately 1 km north of Gallaher Road. The primary source of surface water is the Clinch River, which is approximately 1.5 km northeast of Union Church.

X-10 Reference Location - Jones Island (Clinch River)

The selected reference location for X-10 releases was in the area of Jones Island, which is approximately 5 km southwest of the site. This area represents the closest location off reservation from X-10, and is also along a predominant wind direction. The Task 6 assessment included evaluation of air exposure pathways from X-10 releases, soil-related pathways based on maximum soil concentrations measured near the reference location, and surface water pathways reflecting consumption of fish from and recreational use of the Clinch River.

Due to the complex terrain surrounding the Y-12 facility, any analytical approach to estimating air concentrations at Scarboro that did not reflect the effects of Pine Ridge would lead to overestimation of the fraction of Y-12 releases that were transported to the Scarboro community. An alternative approach using measured uranium air concentrations at Scarboro was devised for use on this project. By relating air concentrations measured at Scarboro from 1986 through 1995 with Y-12 uranium release estimates for the same years, an empirical relative concentration (χ/Q) relationship was described. This relationship was then applied to all annual release estimates (1944–1995) to generate estimates of annual average air concentrations at Scarboro. An air dispersion model was used to estimate concentrations at the reference locations from K-25/S-50 and X-10 releases.

The two main surface water bodies addressed in this analysis are the Clinch River and EFPC. Estimates of uranium concentrations in these surface water bodies were derived from available environmental monitoring data. Estimates of soil concentrations were based on limited measurements compiled over the years of interest. Co-location of soil concentrations and reference locations was not always possible, as sampling locations used for soil measurements were selected based on the monitoring requirements for the facility and were not specific to a community. Therefore, the Task 6 team selected measured soil concentrations from locations closest to each reference location.

Once concentrations of uranium in the applicable environmental media had been quantified, the next step was to evaluate the potential significance of those concentrations. In the case of uranium, which can be chemically toxic as a heavy metal as well as hazardous as a radioactive material, this was done by estimating the radiation doses that could have been received by off-site populations and the total quantities (masses) of uranium that they could have taken into their bodies. Radiation dose estimates were then translated into screening indices, and uranium intakes were used to estimate levels of the metal that might have been present in sensitive body organs, such as the kidneys. These body burdens were compared to published data that indicate the levels above which uranium, as a toxic heavy metal, can start to cause adverse health effects in exposed individuals. These approaches represent conservative estimates of the potential health effects associated with the releases. As described below, different levels of conservatism were maintained in the screening level evaluation of potential exposures to maximum individuals and those exposed under more typical conditions.

This screening assessment evaluated the potential health effects to the individuals that have lived in areas surrounding the ORR. Estimates of material intake were made for individuals living at three selected reference locations. The screening methodology employed a two-tiered approach to assessing screening indices. The Level I assessment focused on the maximally exposed individual, and represents a conservative assessment of uranium screening indices. The second assessment tier (Level II) represents more typical exposures and yielded less conservative screening indices.

Because of the paucity of historical measurements of uranium in the soil near Scarboro and the lack of complete documentation of the methods used for some of the measurements that are available, some special considerations entered into the assessment of doses to Scarboro residents. The assessment used uranium concentrations measured in surface soil/sediment samples from the EFPC floodplain. The best available measurements were made in studies conducted in the 1980s, and the results were reported as uranium concentrations in units of parts per million (ppm). Detailed information about these data is not available, most significantly the concentrations of the specific uranium isotopes that

SCREENING INDICES

The screening indices in this report represent estimates of the potential human health impacts from the releases estimated for the three complexes. he screening indices are compared to the decision guide established by Oak Ridge Health Agreement Steering Panel (ORHASP) to determine if further work is warranted to estimate the human health risks from past uranium releases.

were present. Evidence of earlier soil sampling in Scarboro was not located during the Task 6 investigation. The project team consulted with DOE and current and retired site contractor personnel, who were unable to supply more information regarding the abundance of the uranium isotopes in the soil samples or determine if earlier soil measurements were made in Scarboro.

In the most conservative Level I assessment, the maximum reported value of 70,000 pCi kg^{-1} ^{238}U from the EFPC floodplain was used, and the isotopic mixture of natural uranium was assumed in calculating a corresponding $^{234/235}U$ concentration of 76,000 pCi kg^{-1}. In the Level II assessment, a reported average value of 26 ppm total uranium from the EFPC floodplain was converted to uranium isotope concentrations using similar assumptions. The value of 26 ppm converts to concentrations of 14,000 pCi kg^{-1} $^{234/235}U$ and 12,000 pCl kg^{-1} ^{238}U. The $^{234/235}U$ component of the uranium is most important in terms of doses delivered from uranium exposure, particularly for pathways involving irradiation of the body from contamination outside of the body. The second level of screening was considerably less conservative than the Level I analysis; less conservative "Level II" values were used for various exposure parameters (consumption rates, fractions of foods contaminated, etc.) than were used in the Level I screening assessment. The goal in Level II assessments is to remove known sources of conservative bias. For soil concentrations, an average value was used in Level II compared to a maximum measured value used for the Level I assessment. Because of the scarcity of information regarding estimates of uranium concentrations in the environment over the period of interest, some conservatism was maintained in the uranium concentration estimates used in Level II screening to ensure that hazards to a significant portion of the potentially exposed population were not underestimated. Conservatism was probably also introduced by the use of 1980 EFPC floodplain measurements to represent concentrations at Scarboro, which is outside of the floodplain. As such, the second level of screening may be more appropriately called a Refined Level I analysis. The data that are currently available are not sufficient to support a defensible analysis of average or typical exposures to members of the Scarboro community from the community's inception to the present.

A significant factor in the decision to maintain a conservative value of soil concentration in Level II screening was the uncertainty concerning the level of ^{235}U enrichment in the soil represented by the value of 26 ppm total uranium. Because of this uncertainty, the concentration corresponding to 14,000 pCi kg^{-1} $^{234/235}U$ (or 26,000 pCi kg^{-1} total uranium) was used. To illustrate how the overall results of the assessment would differ if lower soil concentrations were assumed, screening indices were also calculated for soil concentrations of 7,000 and 2,000 pCi kg^{-1} total uranium.

Annual radiation doses from uranium intake and external exposure were calculated for the adult age group for each screening assessment and then converted to screening indices using a dose-to-risk coefficient of 7.3% Sv^{-1}. The individual dose conversion factors for ^{234}U, ^{235}U, and ^{238}U were used in estimating internal and external radiation doses from uranium contamination in the environment. Screening indices for Task 6 are presented in Table ES-3.

Table ES-3: Summary of the Screening Indices from Each Task 6 Assessment
(Screening Indices in bold exceed the decision guide of 1×10^{-4})

Assessment	LEVEL I	LEVEL II
Exposures at the Scarboro Community due to Releases from the Y-12 Complex	**1.9×10^{-3}**	8.3×10^{-5}
Exposures at the Union/Lawnville Community due to Releases from the K-25/S-50 Complex	**2.7×10^{-4}**	4.0×10^{-5}
Exposures at the Jones Island Community due to Releases from the X-10 Complex	7.6×10^{-5}	NA

NA: Not Assessed, as the Level I assessment result was below the decision guide

The Scarboro community was associated with the highest total screening index attributable to uranium releases from the Y-12 facility. The screening indices were 1.9×10^{-3} for the Level I assessment and 8.3×10^{-5} for the Level II assessment. These values translate into potential health impacts (excess fatal and nonfatal cancer and severe hereditary effects) of about 2 in 1,000 and 8 in 100,000, respectively. While the overall Level I screening index for the Scarboro community is above the ORHASP decision guide of 1 in 10,000, the Level II value is below that guide value. This indicates that the Y-12 uranium releases are candidates for further study, but that they are not high priority candidates for further study.

The Y-12 screening indices are most sensitive to $^{234/235}$U and ^{238}U concentrations in soil, $^{234/235}$U concentrations in air, and $^{234/235}$U concentrations in water. The major pathways of concern include the ingestion of vegetables grown in contaminated soil, external doses from $^{234/235}$U in soil, the inhalation of airborne $^{234/235}$U, and consumption of meat and milk from cattle raised on contaminated pasture. The Level II result for the Y-12 assessment in Table ES-3 is based on a $^{234/235}$U soil concentration of 14,000 pCi kg^{-1} (or 26,000 pCi kg^{-1} total uranium). Using a soil value of 7,000 pCi kg^{-1} total uranium yields a screening index of 5.8×10^{-5}, a 30% reduction from the screening index calculated for the Level II assessment. A 2,000 pCi kg^{-1} total uranium soil concentration produces an index of 5.1×10^{-5} , a 40% reduction. Note that even though these alternative soil concentrations (7,000 and 2,000 pCi kg^{-1}) represent 73% and 92% reductions in soil concentrations respectively, the reduction in the screening index for Level II is not in proportion. The soil pathways represent only 38% of the total screening index from $^{234/235}$U and 51% from ^{238}U. Since the concentrations in air and water were not changed for the alternative evaluations, a given reduction in soil concentration will not equal a corresponding reduction in the total screening index. Further characterization of the extent of uranium contamination in soils should be a component of any future studies of potential exposures to residents of the Scarboro community.

Air concentrations at the Scarboro community were estimated using the empirical χ/Q approach. This approach used 10 years of measurements of uranium in ambient air at Scarboro with estimates of annual

releases from the Y-12 Plant to calculate an effective annual dispersion factor that was then used to approximate concentrations for earlier years. It is important to remember that this approach is reliant upon Scarboro air concentration measurements, which are available only for the period 1986 to 1995, and release estimates for the same years. Differences in operations and release point distributions or characteristics for periods before 1986 could call into question the applicability of the empirical χ/Q value to earlier years. In addition, information was gained late in the project that indicated that Y-12 uranium releases for some of the years used for development of the empirical χ/Q value may have been understated due to omission of some unmonitored release estimates. It was not possible within the time frame of this project to evaluate the new data sufficiently to warrant its use in this assessment. If Y-12 uranium releases during years used to develop the empirical χ/Q value applied in this assessment were indeed under reported, that would mean that the associated empirical χ/Q values were overestimated, and concentrations at Scarboro that were estimated using that approach were in turn overestimated. It is impossible to gauge the magnitude of any biases potentially introduced by this possible under reporting without closely evaluating the bases of the release estimates during the associated years in the 1980s and 1990s.

For the K-25/S-50 assessment, the total screening index for Union/Lawnville from the Level I assessment (3 in 10, 000) exceeded the decision guide. The less conservative Level II screening result did not exceed the guide. This indicates that the K-25/S-50 uranium releases are candidates for further study, but that they are not high priority candidates for further study. For the Level I screening, the air pathways account for approximately 23% of the screening index; 76% of the total screening index was attributable to the soil pathways. With limited data available to characterize the soil concentrations at Union/Lawnville, these assessments are the best estimates of health impacts possible within the scope of Task 6.

The assessment of releases from X-10 did not yield Level I screening indices that exceed the decision guide for Level I. The releases from X-10 warrant a lower priority given the pilot-plant nature and relatively short duration of most X-10 uranium operations. Uranium in liquid effluents from X-10's White Oak Creek to the Clinch River were addressed in the Task 4 component of the Oak Ridge Dose Reconstruction. The Task 4 preliminary screening analysis for radionuclides in Clinch River water and sediments is described in Section 3 of the Task 4 report. In that report, ^{235}U and ^{238}U are identified as contaminants that were included in the screening analysis. Based on the preliminary Task 4 screening, these two uranium isotopes are identified as being among those 16 contaminants that were assigned low priority for further study based on comparison of screening results with the decision guide of 1×10^{-5} excess lifetime cancer risk applied to individual radionuclides within the Task 4 screening.

Estimates of annual-average intakes of uranium by inhalation and ingestion were also used by the project team to evaluate the potential for health effects due to the chemical toxicity of uranium compounds, specifically for damage to the kidneys. Using estimated annual average uranium intake rates via inhalation and ingestion at the Scarboro community, the project team used biokinetic modeling of uranium retention and excretion in the human body to estimate annual kidney burdens (uranium concentrations in kidney tissue) over the years of interest. Predicted uranium burdens were compared to toxicity thresholds reported in the scientific literature.

For the conservative Task 6 screening for chemical toxicity, uranium was assumed to be in its most soluble form (such as uranyl nitrate), and safety factors were included to minimize the potential for underestimation of the potential for toxic effects. As shown in Figure ES-4, estimated kidney burdens resulting from simultaneous intake of uranium by ingestion and inhalation under the Scarboro assessment do not exceed an effects threshold criterion of 1 microgram of uranium per gram of kidney tissue (1 Fg g^{-1}) proposed by some scientists, but do exceed an effects threshold criterion of 0.02 Fg g^{-1} advocated by others who have studied uranium effects in the kidney.

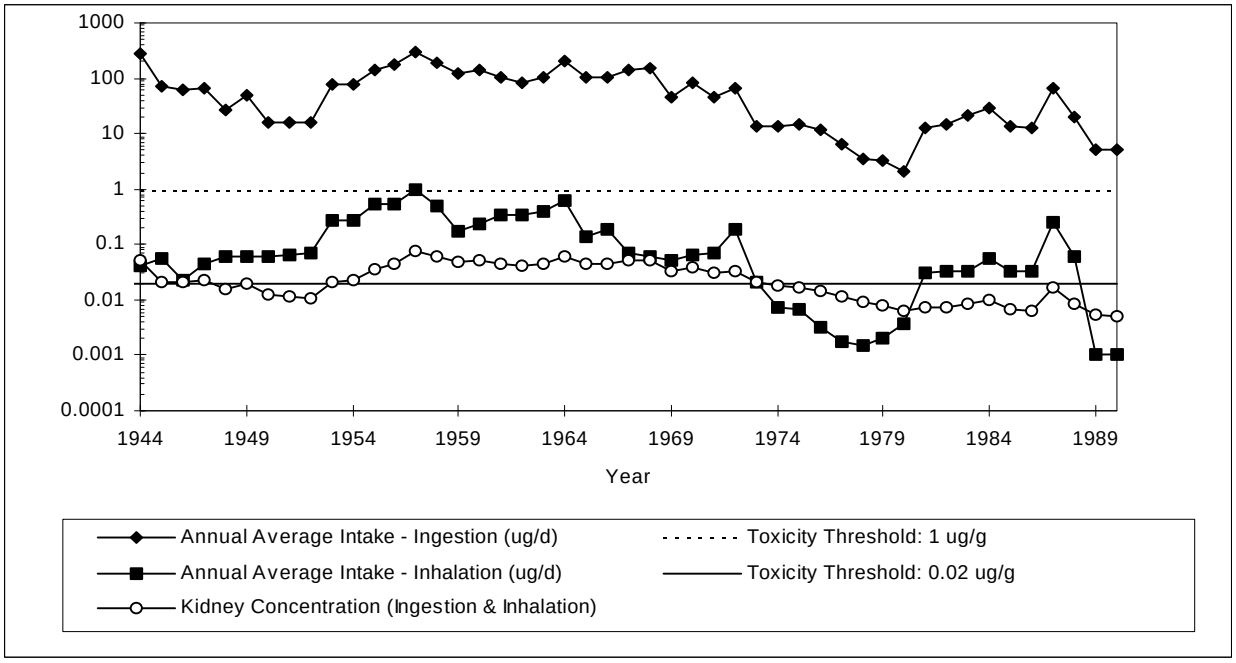


Figure ES-4: Annual Average Uranium Intakes Via Simultaneous Ingestion and Inhalation (Fg d^{-1}) with Resulting Kidney Burdens (Fg g^{-1})
Calculated for the Y-12 Assessment, at the Scarboro Community

Estimates of annual-average intakes of uranium were also compared to the USEPA oral Reference Dose (RfD) as an alternative method of evaluating the potential effects of ORR uranium exposures. The RfD of 3×10^{-3} mg kg^{-1} d^{-1} is primarily based on animal studies, and is conservatively set at a level to ensure that there are no adverse effects on renal function. Using estimated annual-average daily uranium intake rates via inhalation and ingestion at the Scarboro community, the project team determined annual Hazard Indices (HIs) by dividing the annual-average daily intake rates by the RfD. Hazard Indices are presented in Figure ES-5. The average HI is well below unity and suggests that further study of heavy metal toxicity from past ORR uranium exposures does not warrant high priority.

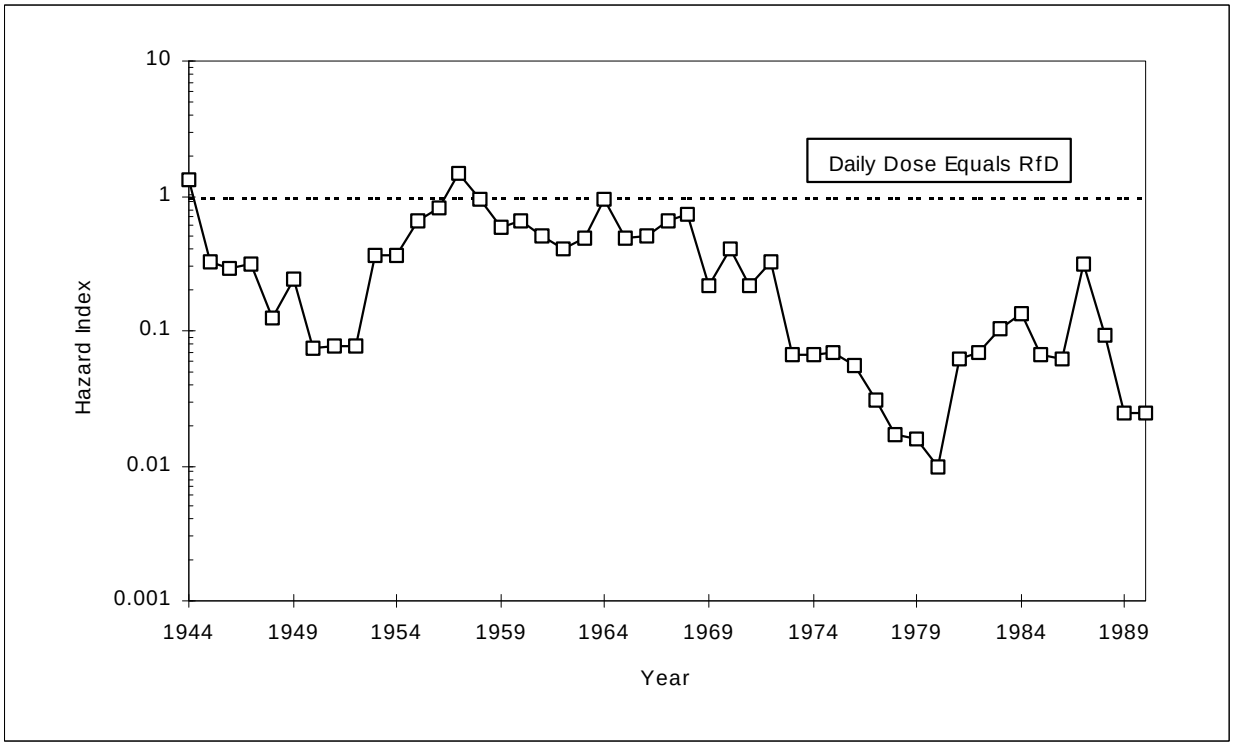


Figure ES-5: Annual Average Hazard Indices for a 70 kg Person and an Oral RfD of 3×10^{-3} mg kg^{-1} d^{-1}

Based upon the experience of the project team in conducting the Dose Reconstruction Feasibility Study and the Task 6 evaluation, a number of areas have been identified that are logical next steps in the evaluation of potential health effects from Oak Ridge uranium releases. These areas, which are identified throughout this report, deal with components of the study that the project team believes are significant contributors to the overall uncertainty of the results of the Task 6 screening evaluation. These areas should be examined if the evaluation of Oak Ridge uranium releases is to proceed beyond the screening stage, and into a stage of refined evaluations that will likely include uncertainty and sensitivity analyses to assist in the decision making process.

Activities that should be evaluated for possible follow up work include:

(1) Additional records research and data evaluation regarding S-50 Plant operations and potential releases.

(2) Additional searching for and review of effluent monitoring data for Y-12 electromagnetic enrichment operations from 1944 to 1947 and data relating to releases from unmonitored depleted uranium operations in the 1950s through the 1990s.

(3) Uncertainty analysis of the Y-12 uranium release estimates derived in this study.

(4) Review of additional data regarding unmonitored K-25 uranium releases. In this and other areas, new information continues to become available each month, and it should be reviewed so that we are assured that analyses thought to be bounding are in effect sufficiently conservative.

(5) Refinement of the approach used to evaluate surface water and soil-based exposure concentrations. This refined analysis could possibly involve shifting to a source term-based approach rather than one based on environmental measurements. This would include review of release estimates to assure that the release estimates used in the screening assessments were appropriate.

(6) Evaluation of the effects of the ridges and valleys that dominate the local terrain surrounding Y-12 and Scarboro and investigation of alternative approaches to estimate air concentrations at Scarboro with an emphasis on identifying additional monitoring data. Evaluation of the uncertainty associated with air concentrations would provide upper and lower bounds of confidence in the estimates.

(7) Performance of a bounding assessment of the amounts of uranium that were handled at the X-10 site, for comparison with Y-12 and K-25/S-50, and for evaluation of the feasibility of generating a more complete air source term for uranium.

(8) Improvement of the exposure assessment to include region-specific consumption habits and lifestyles, identification of likely exposure scenarios instead of hypothetical upper bound and typical assessments, and inclusion of uncertainty analysis to provide statistical bounds for the evaluations of risk.

(9) Refinement of the chemical toxicity evaluation, possibly to include other approaches/ models and an uncertainty analysis.

1.0 INTRODUCTION

Starting in the early 1940s, large quantities of uranium were processed on the Oak Ridge Reservation (ORR) to enrich the uranium-235 (^{235}U) component for nuclear weapon component production, and in various research and development projects (ChemRisk 1993a). The ORR is located approximately 25 miles west of Knoxville in eastern Tennessee. Major complexes bearing the code names K-25, S-50, X-10, and Y-12 were located on the 58,000-acre Reservation. Figure 1-1 shows the locations of the Y-12, K-25 and ORNL complexes; S-50 was located adjacent to the K-25 site and X-10 is located within the area designated by ORNL. Photographs 1, 2, and 3 depict the Y-12, K-25, and S-50 sites, respectively.

- The K-25 Site was the home of operations that enriched uranium in its ^{235}U component using the gaseous diffusion process from 1945 to 1985.

- The S-50 Plant enriched uranium using the liquid thermal diffusion process for only one year, from 1944 to 1945.

- Built for development of methods for separation of plutonium from uranium reactor fuel, the X-10 Site later was the home of a variety of pilot-scale operations to chemically separate desired products from irradiated uranium and other nuclear materials.

- While Y-12 Plant operations from 1944 to 1947 centered around enrichment of uranium by the electromagnetic process, facilities were converted to perform nuclear weapon component fabrication from 1952 to 1995.

In the Oak Ridge Dose Reconstruction Feasibility Study, preliminary investigations and screening calculations indicated that uranium was not among the list of contaminants that warranted highest priority for detailed investigation of potential off-site health effects (ChemRisk 1993b). Because of the prominence of uranium in the historical operations of each Oak Ridge complex, these results were counterintuitive to many people. Because of this, Task 6 of the Oak Ridge Dose Reconstruction was designed to examine Oak Ridge uranium operations and associated effluent monitoring records in more detail to determine if uranium releases from the ORR likely resulted in off-site doses that were high enough to warrant further study.

THE INTENT OF THE TASK 6 STUDY

The intent of the Task 6 study was to evaluate the quality of historical uranium effluent monitoring data, and to confirm or modify previous uranium release estimates for the period from 1944 to 1995 for all three complexes on the Oak Ridge Reservation. The main results of the study are screening-level estimates of potential health impacts to people living near the Reservation. These results, which will be called "screening indices", are conservative estimates of potential heath impacts and are intended to be used with the decision guide established by Oak Ridge Health Agreement Steering Panel (ORHASP) to determine if further work is warranted to estimate the human health risks from past uranium releases.

Task 6 investigators evaluated the quality of historical uranium effluent monitoring data, modified previous uranium release estimates for the period from 1944 to 1995 based on additional source term information, and developed screening-level estimates of potential doses and health risks to people living near the Reservation. The Task 6 investigation used a five-step approach, which is depicted in Figure 1-2 and can be summarized as follows:

(1) Information that described uranium uses and releases on the ORR was collected to identify important release sources and to focus the Task 6 investigation on relevant effluent monitoring data.

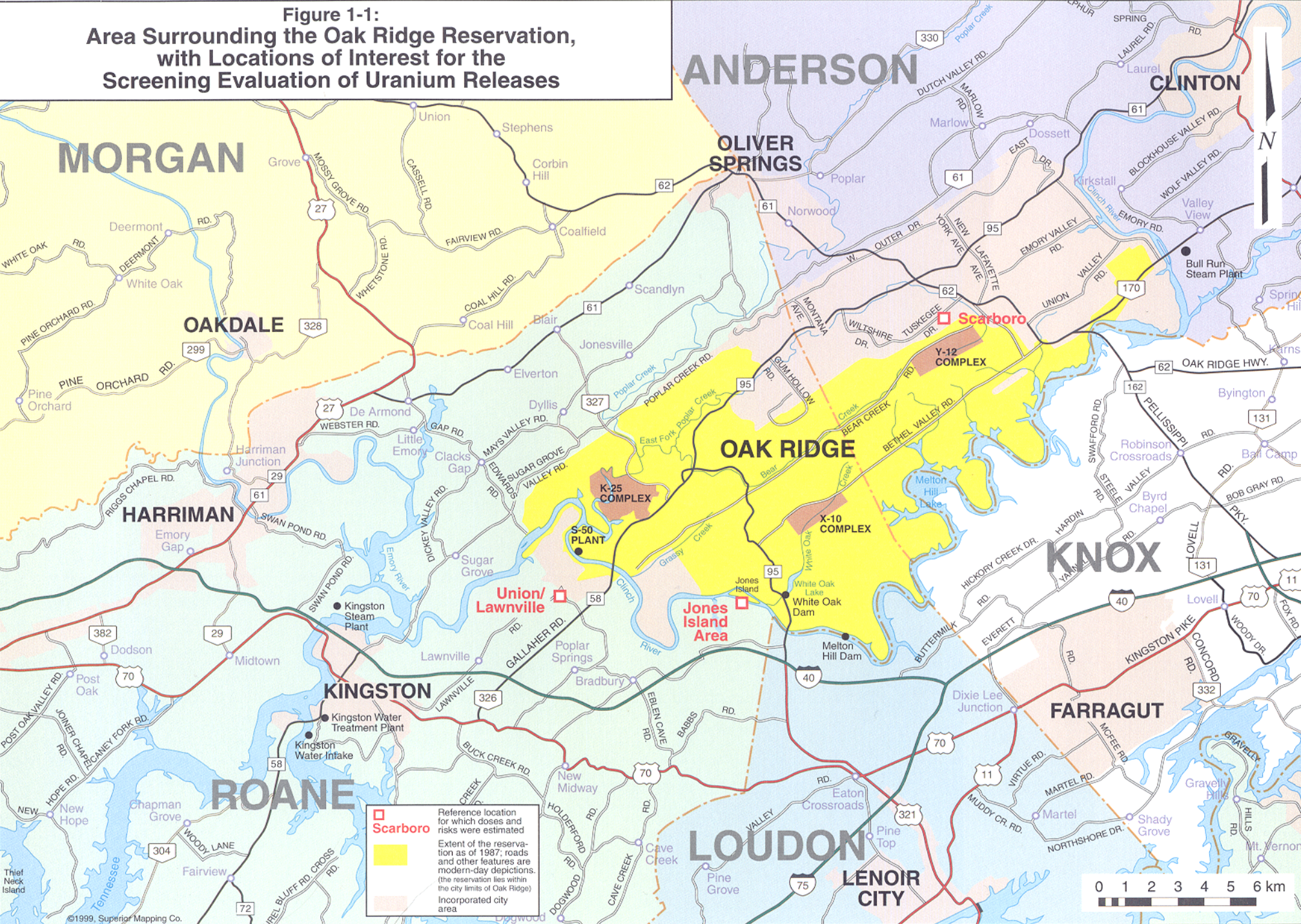
(2) Effluent monitoring data were evaluated for quality and for consistency with previous U.S. Department of Energy (DOE) historical uranium release reports. This step also involved determination of whether or not the available information suggested a need to modify DOE's estimates (USDOE 1988) for use in Task 6 screening.

(3) Since the evaluation of effluent monitoring data showed that a significant amount of information regarding monitored and unmonitored air releases was not taken into account in the preparation of previous DOE estimates, revised estimates of airborne uranium releases were prepared using the more complete data set now available to the project team.

(4) Air dispersion modeling for the K-25 and X-10 assessments and empirical dispersion factor ("χ/Q") values for the Y-12 assessment were used to estimate annual-average uranium air concentrations at areas near these sites where people have historically lived ("reference locations"). For each reference location, uranium concentrations in surface water and soil were also estimated from environmental monitoring data for use in screening calculations.

(5) A screening-level evaluation of potential off-site uranium exposure was performed by calculating uranium intakes, associated radiation doses, and the potential increases in health effects in people living near the ORR as a result of releases that occurred from 1944 through 1995. These screening results (referred to as screening indices) represent conservative or upper bound estimates of potential health effects, and are intended to be used for the sole purpose of determining whether or not a complete and thorough dose reconstruction study of ORR uranium operations is warranted.

Figure 1-1:
Area Surrounding the Oak Ridge Reservation, with Locations of Interest for the Screening Evaluation of Uranium Releases



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PHOTOGRAPH 1: AERIAL PHOTOGRAPH OF THE Y-12 PLANT (1990)

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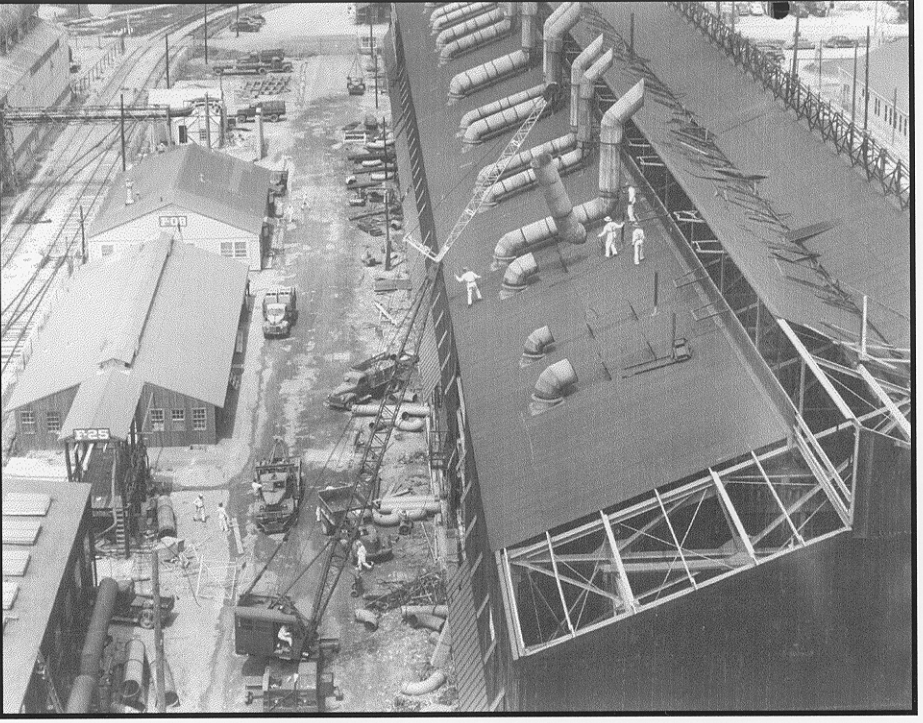
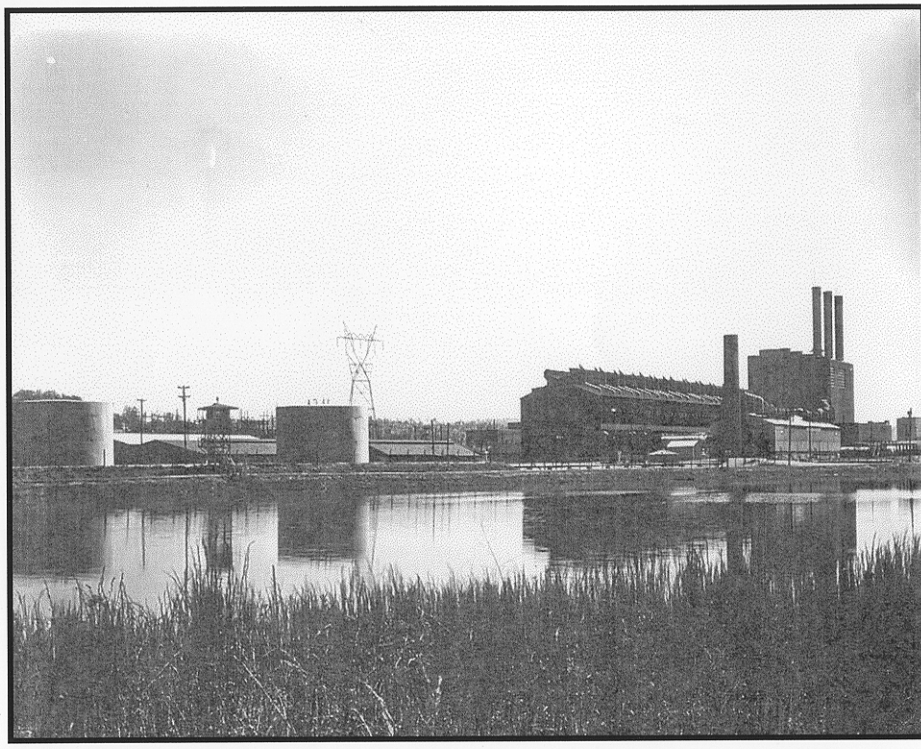
PHOTOGRAPH 2: AERIAL PHOTOGRAPH OF THE K-25 PLANT (1990)





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PHOTOGRAPH 3: VIEWS OF THE S-50 PLANT (1946)

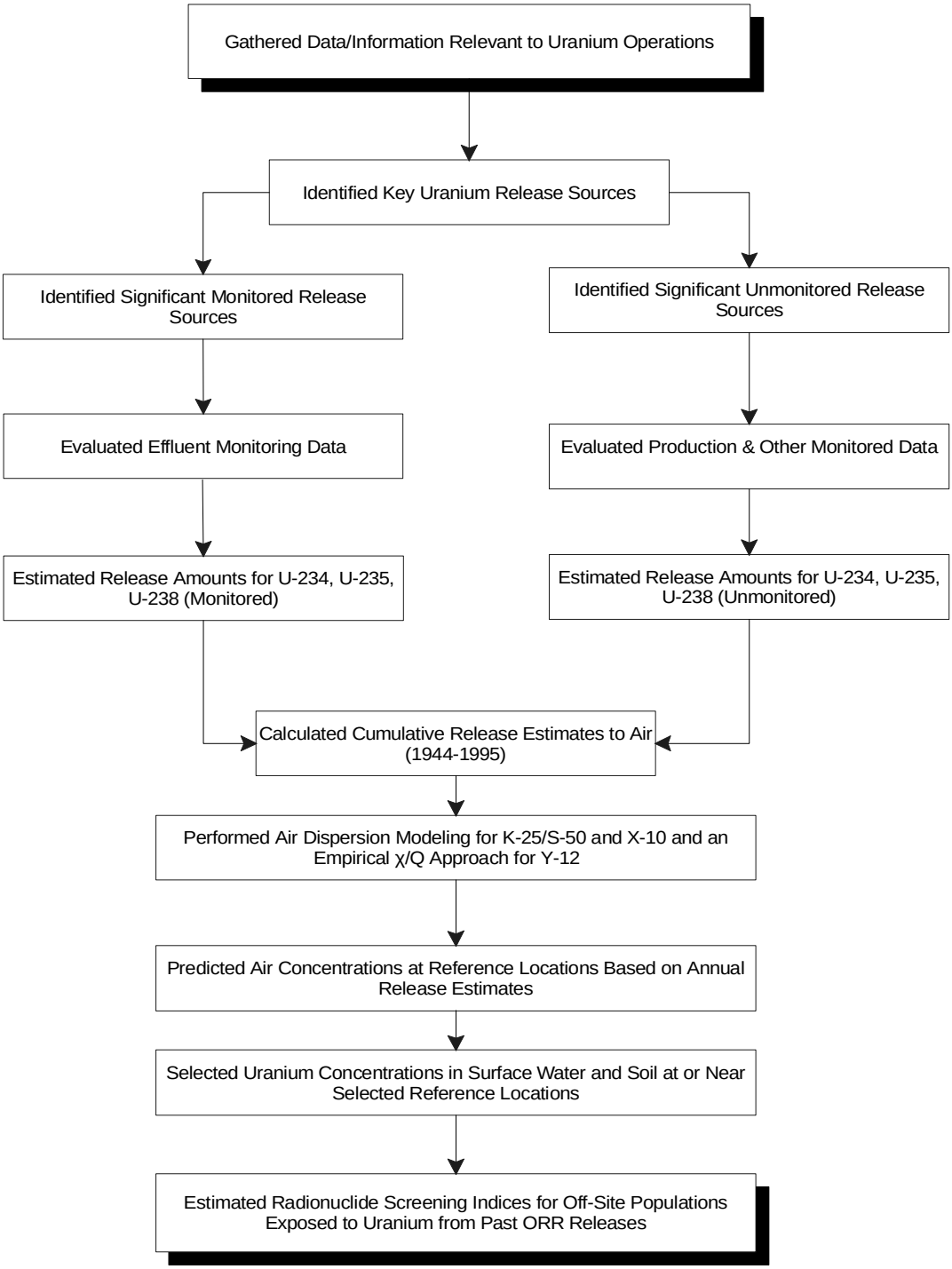


Figure 1-2: The Task 6 Approach

1.1 Sources of Information for Task 6

An extensive information gathering and review effort was undertaken by the project team in searching for information related to historical uranium operations at the K-25, S-50, and Y-12 sites. Thousands of documents were searched, and many active and retired workers were interviewed to obtain information relevant to Task 6. The following techniques were used to gather relevant information for Task 6:

- Review of documents identified from keyword searches of in-plant computer databases,
- Random searches of documents from in-plant computer databases,
- Directed searches of document repositories for uranium effluent monitoring data and descriptions of uranium operations and release points,
- Interviews with key active and retired workers knowledgeable about historical uranium operations and effluent monitoring,
- Review of engineering drawings to identify uranium processes and operations and characterize associated release points, and
- Verification of release points from aerial photographs taken throughout the period of plant operations.

Many original documents of relevance to Task 6 were found in various document centers on the ORR and in off-site repositories such as the Federal Records Center in Atlanta, Georgia. Particular attention was directed at those documents and information sources that related to characterization of uranium uses, mechanisms by which uranium was released to the off-site environment, and effluent monitoring measurements and practices. Nearly all of the relevant information was obtained from the following sources:

- Monthly and quarterly health physics and industrial hygiene reports,
- Effluent sampling procedures,
- Analytical procedures used to measure uranium in effluent samples,
- Exhaust duct or stack sampling logbooks,
- Miscellaneous reports that describe uranium production operations,
- Logbooks of ventilation system tests and measurements,
- Miscellaneous reports that describe uranium monitoring practices and data,
- Incident reports,

- Accident investigation reports,
- Nuclear material accountability records (uranium inventory information),
- Monthly and quarterly reports of airborne effluent releases,
- Monthly and quarterly reports of waterborne effluent releases,
- Quarterly and semi-annual site environmental monitoring plant reports, and
- Interviews with active and retired plant employees.

Each interviewee typically began by relating his or her personal employment history and highlighting specific involvement with uranium operations and effluent monitoring. Examples of the types of questions asked by project investigators are:

- What were the primary uranium operations and buildings that you are familiar with?
- Were you involved with uranium effluent monitoring? When did the plant first begin stack monitoring? When did the plant first begin surface water monitoring? Who or what department or division was responsible for uranium effluent monitoring data or generation of uranium release estimates?
- How were effluent estimates reported? How often were results reported (daily, weekly, etc.)? What department provided these reports? Do you know where to find documents or other information that describes effluent monitoring practices and uranium release estimates? How did reporting practices changed over the approximately fifty-year history?
- Do you recall any accidental or nonroutine events that resulted in releases of uranium from production operations or storage areas at the plant?
- Can you provide names of other individuals that are knowledgeable about uranium operations and uranium effluent monitoring practices?

A list of the individuals who were interviewed in the course of Task 6 investigations is provided in Appendix L.

1.2 Indications from Reported Releases and Project Investigations

In May 1988, DOE published the Historical Radionuclide Release Report, ORO-890 (USDOE 1988). This report presented estimates of radionuclide releases from the K-25, X-10, and Y-12 sites and annual summaries of radionuclide "releases" through on-site burial and airborne and waterborne effluents. The report did not address releases from the S-50 Plant. Only K-25 and Y-12 provided airborne and waterborne uranium release estimates. X-10 provided estimates of uranium buried on site, but airborne

and waterborne effluent reporting was limited to fission products, activation products, unidentified transuranic nuclides, and unidentified beta (waterborne) or alpha (airborne) emitting radionuclides.

Releases of uranium at X-10 came primarily from the chemical processing of reactor fuel and other nuclear materials for separation of desired radionuclides. These processing pilot programs or "campaigns" were quite short in duration compared to production operations at K-25 and Y-12. By their nature, chemical separation processes were associated mostly with uranium compounds or metal dissolved or entrained in water, and operations were generally conducted so that uranium wastes ("metal wastes") were captured and separately retained so that the uranium could be recovered. As an illustration of this, a "metal recovery plant" became operational in 1952 to process uranium-bearing wastes. By 1960, more than 130 tons of uranium had been recovered (Feige et al. 1960). It is clear, however, that some waterborne uranium was released from X-10 waste processing systems to White Oak Creek. Task 4 of the Oak Ridge Dose Reconstruction evaluated radionuclide releases from White Oak Creek to the Clinch River in detail. At the same time, for the sake of completeness of the Task 6 screening evaluation, exposures at the reference location for the X-10 site via surface water pathways were estimated based on historical measurements of uranium in appropriate environmental media as described in Section 3.

While X-10 uranium releases appear to have been primarily to surface waters, some airborne releases also occurred. Unfortunately, airborne uranium effluent monitoring data are not available for the X-10 operations of interest. In the Dose Reconstruction Feasibility Study, historical uranium releases to the atmosphere were estimated for (1) early chemical separation of plutonium [1944-1945], (2) radioactive lanthanum separation operations [1944-1956], (3) processing of freshly-irradiated thorium using the Thorex process [1956-1957], and (4) ruptures of Graphite Reactor fuel slugs [1944-1948] (ChemRisk 1993b). Appendix H discusses aspects of the Dose Reconstruction Feasibility Study that are relevant for this discussion. For Task 6 screening of airborne releases from X-10, ^{235}U and ^{238}U release estimates from the Dose Reconstruction Feasibility Study were used. In cases where the Feasibility Study provided estimates for peak years of processing, these peak estimates were replicated through all years of duration for each operation of interest. If the analysis of uranium releases from the ORR is carried beyond the screening stage, a more detailed investigation of airborne uranium releases from X-10 operations may be warranted. After review of the information and resources available to the project team, it was determined that Task 6 investigations should focus on the K-25, S-50, and Y-12 plants as the dominant sources of airborne uranium releases.

The project team has determined that the May 1988 DOE uranium release estimates are based on incomplete effluent monitoring data and nuclear material accountability records. As such, they are considered an inadequate basis for estimating potential doses received by people living near the ORR from 1944 to 1995. The project team used additional information obtained during the investigation to independently reconstruct estimates of how much uranium was historically released from the Oak Ridge facilities. The Task 6 estimates are based on a much more complete set of original records and detailed uranium effluent monitoring data than those previously presented in the 1988 DOE report. These revised release estimates are considered a more defensible basis for estimating potential historical risks for off-site populations.

1.3 Organization of this Report

This report presents the results of the Task 6 investigation. Organized in four main sections, this report contains the following information:

- Descriptions of K-25, S-50, and Y-12 uranium processing operations and important monitored and unmonitored release sources.

- Descriptions of available uranium effluent monitoring data, calculations used by the project team to develop revised K-25, S-50, and Y-12 air release estimates for both monitored and unmonitored releases, and estimates of uranium concentrations in surface water and soil.

- Descriptions of the air dispersion modeling and other approaches used by the project team to describe the movement of airborne uranium from the ORR to off-site locations, and to predict air concentrations at these off-site reference locations.

- Risk screening results and comparisons with the decision guide that have been proposed for use within this project.

- Discussion of areas of the Task 6 assessment (such as aspects of source term development and site-specific exposure evaluation) that the project team believes are top candidates for further investigation if the analyses are to continue beyond first-level screening.

Additional information regarding ORR uranium operations, uranium releases to the off-site environment, and the approaches used by the Task 6 team to evaluate effluent monitoring data and reconstruct uranium releases can be found in appendices of this report. These appendices are referenced throughout this report.

1.4 Summary of Y-12 Operations

The Oak Ridge Y-12 Plant was built for the U.S. Army Corps of Engineers in 1943, as part of the Manhattan Project. Located at the eastern end of Bear Creek Valley, the Y-12 complex is within the corporate limits of the city of Oak Ridge and is separated from the main residential areas of the city by Pine Ridge. The plant is bordered on the south by Chestnut Ridge and on the north by Bear Creek Road and Pine Ridge. While the main Y-12 production area is about 0.6 miles wide by 3.2 miles long, covering roughly 825 acres, the plant and its fenced buffer area total about 4,860 acres (Gosling 1990). The site contains roughly 240 principal buildings, about 18 of which were directly involved with processing and/or storage of uranium compounds (Patton 1963; UCC-ND 1983). During World War II, Y-12 workers produced highly-enriched uranium for use in the first atomic weapons by electromagnetically enriching uranium in its ^{235}U isotope. Starting in the 1950s, Y-12 began large-scale production of nuclear weapon components, including some made of uranium, and continued these operations into the 1990s.

More detailed descriptions of Y-12 uranium operations, buildings, and important uranium releases are presented in Appendix A. Appendix A contains tables and figures that provide a summary of historical operations, effluent monitoring practices, releases sources, and sources of information that are relevant in reconstructing uranium releases to the off-site environment. The key processes and activities associated with uranium at the Y-12 Plant include:

- **Electromagnetic Enrichment (1943 - 1947):** During the war effort, Y-12 enriched uranium in its ^{235}U isotope for use in the first atomic weapons by processing large amounts of uranium tetrachloride in electromagnetic enrichment devices called "calutrons." These operations were housed in "Alpha" buildings (Buildings 9201-1, 9201-2, 9201-3, 9201-4, and 9201-5) and "Beta" buildings (Buildings 9204-1, 9204-2, 9204-3, and 9204-4) that contained the first and second stages, respectively, of the enrichment processes.

- **Feed Preparation for Enrichment Operations (1943 - 1947):** Feed preparation involved conversion of large quantities of uranium oxides (namely UO_2, UO_3, and U_3O_8) into uranium tetrachloride (UCl_4), the feed material for electromagnetic enrichment in the calutrons. The majority of these operations were housed in Buildings 9202, 9203, 9206, and 9212.

- **Uranium Recovery and Recycle Operations (1944 - 1951):** Y-12 had an elaborate system of mechanical and chemical processes to recover and recycle uranium feed and product material that had ^{235}U content worth recovering. The majority of these operations were housed in Buildings 9202, 9203, and 9206.

- **Uranium Salvage Operations (1947 - 1951):** After the war, calutron parts and feed preparation and material recovery equipment containing small amounts of uranium were cleaned and decontaminated. Some uranium was recovered for future use, some contained in wash fluids was discharged to East Fork Poplar Creek, and scraps and materials that could not be decontaminated were buried within the ORR. The majority of these operations were housed in Buildings 9206, 9207, and 9211.

- **Uranium Preparation and Recycle for Weapon Component Operations (1949 - 1995):** Uranium for weapon production was first processed in recovery, purification, and conversion operations. From approximately 1949 to 1964, Y-12 received cylinders of 93.5 percent enriched uranium hexafluoride as feed material for nuclear weapon parts manufacturing. Once purified and converted to its metal form, uranium was transferred to metal processing operations for forming and shaping into weapon part configurations. After 1964, the majority of enriched uranium processed at Y-12 was recycled from nuclear weapon stockpiles. Uranium recycle and purification processes continued up through present day operations. The majority of these operations were housed in Buildings 9202, 9206, and 9212.

Uranium Forming and Machining for Weapon Component Operations (1949 - 1995): Formed uranium metal parts were machined into finished weapon parts and then transferred to Y-12 assembly operations. Numerous buildings were needed to support these diverse operations and were frequently modified to meet changes in production needs. The majority of these operations were housed in Buildings 9201-5, 9204-4, 9215, and 9998.

Weapon Component Assembly Operations (1952 - 1995): Weapon parts were assembled into finished products, inspected and tested against design criteria, and then shipped off-site. The majority of these operations were housed in Buildings 9204-2 and 9204-2E.

1.5 Summary of K-25 and S-50 Operations

Construction of the K-25 uranium enrichment facility began in 1943, and the facility was operational by January 1945. The K-25 Site is located near the western end of the ORR, along Poplar Creek near where it meets the Clinch River. The primary mission of K-25 was to enrich uranium in its ^{235}U component by the gaseous diffusion process. Uranium hexafluoride (UF_6) gas was fed into a series of vessels that formed the gaseous diffusion cascade. UF_6 with enhanced ^{235}U content was withdrawn near one end of each cascade, and UF_6 with decreased ^{235}U content ("depleted" uranium) was discharged at another location.

Located along the Clinch River near the K-25 Site, the S-50 Site was the location of a liquid thermal diffusion plant that operated from October 1944 to September 1945. Task 6 investigators searched for and reviewed available documentation of S-50 Site operations. Very little information was found concerning uranium mass balances, inventories, accidental and non-accidental releases, environmental sampling, or release fractions for the 12 months of S-50 operations. If the Task 6 analysis is to proceed beyond the screening stage, additional investigation would likely be warranted in the form of searching for more information on S-50 Plant operations and more rigorous characterization of the uranium releases that resulted from its one year of operation. Because of their close proximity, the K-25 and S-50 complexes will generally be discussed together in this report.

From the beginning of operations in 1945, K-25 personnel maintained accounting systems for tracking the quantities of uranium that were processed and handled. In 1983, at the request of the DOE, K-25 personnel summarized the quantities of uranium historically received at the plant as well as quantities that were considered lost or unaccounted for (Rogers 1985). Key findings of the study included:

As of the end of September 1983, the total amount of uranium that had been received at K-25 over the previous 39 years was estimated to have been 232,412 metric tons, including 2,119 metric tons of ^{235}U.

Over the same period, the cumulative K-25 inventory deficit (material received or fed to the cascade, but not accounted for in final product, inventory, or wastes) was 168 metric tons of uranium, including 4.8 metric tons of ^{235}U.

Over 50% of the K-25 Site historical uranium inventory deficit can be attributed to feed manufacturing and development of feed manufacturing processes, with most of the remainder (47%) attributed to the gaseous diffusion cascade operations.

The numbers above are applicable to facilities associated with the gaseous diffusion plant only, and do not include operations at the S-50 Plant. The S-50 Plant was located at the K-25 site, but was separately administered.

Information regarding each major process that contributed to uranium releases from the K-25 and S-50 sites is presented in figures and tables that can be found in Appendix B. Each figure in the appendix indicates the location and period of operation for a particular process. Buildings presented in these figures have been shaded differently to indicate the varying levels of ^{235}U enrichment for each facility. Tables found in the same appendix summarize relevant information about each key uranium process or activity, including potential sources of monitored and unmonitored releases and the availability of effluent monitoring data.

The key operations and activities at the K-25 and S-50 sites that involved uranium were:

Liquid Thermal Diffusion Enrichment (S-50 Plant) (1943 - 1945): A liquid thermal diffusion plant was built to determine the economic and technical feasibility of this method of separating ^{235}U from ^{238}U. The plant started operations in October 1944, but was shut down in September 1945 due to excessive equipment failures and resulting releases of uranium to the air and the Clinch River. The S-50 Plant releases were not included in the K-25 DOE release estimates in the past.

Hydrogen Fluoride and Fluorine Disposal (1944 - 1952): A "disposal tower" was used to convert fluorine and hydrogen fluoride, encountered in feed manufacturing and conditioning of cascade component surfaces, to less toxic materials before venting to the atmosphere.

Gaseous Diffusion Enrichment (1945 - 1985): Uranium hexafluoride (UF_6) gas was fed into the gaseous diffusion cascade, ultimately producing UF_6 with a higher concentration of the ^{235}U isotope at the "top" of the cascade. UF_6 depleted in the ^{235}U isotope was discharged at the "bottom" of the cascade.

UF_6 Feed Manufacturing (1952 - 1965): Feed manufacturing was the process that made gaseous UF_6 by converting uranium dioxide (UO_2) to uranium tetrafluoride and then to uranium hexafluoride.

Product and Tails Withdrawal (1945 - 1985): Gaseous UF_6 product and depleted uranium "tails" were removed from the cascade through the product and tails withdrawal facilities. In these facilities, gaseous UF_6 from the vacuum of the cascade was compressed to a pressure greater than 22 psia, cooled to condense into a liquid, and drained into cylinders used for storage and shipping.

- **Uranium Recovery and Decontamination (1944 - 1985):** Equipment used in the gaseous diffusion process was periodically decontaminated to remove gradual deposition of uranium compounds (USDOE 1979). When uranium-contaminated gloves, shoes, and oil sludge was incinerated, the resulting ash was also processed for recovery of uranium.

- **Feed Vaporization (1945 - 1985):** The feed vaporization facilities heated cylinders containing solidified UF_6, thereby converting the material to the vapor phase for feeding to the cascade.

- **Research and Development Activities (1944 - 1985):** Research and development activities at K-25 included fluorination of uranium metal chips to UF_6, processing of zirconium-clad uranium oxide, uranium chemistry research, equipment performance testing, and compressor testing.

- **K-25 Laboratories (1944 - 1985):** A laboratory complex was used to support cascade operations and research and development at the K-25 Site.

- **Toll Enrichment (1969 - 1985):** The Toll Enrichment Facility was placed into operation in January 1969 as a shipping and receiving point for non-DOE owners of UF_6 who sought uranium enrichment services from the K-25 Site. Their uranium was used for fueling of light- water nuclear power reactors throughout the world. From 1969 to 1983, a total of 13,297 of the 2.5-ton product cylinders were shipped to private industry (MMES 1985).

- **Gas Centrifuge Program (1960s - 1980s):** The Gas Centrifuge Program operated from the early 1960s to the mid 1980s. There were 6 facilities that developed and tested the centrifuges which were designed as an improvement on the cascade enrichment process.

2.0 QUANTIFYING HISTORICAL URANIUM RELEASES FROM ORR FACILITIES

The Task 6 investigation focused on independent evaluation of the quantities and qualities of uranium that were released from the main uranium processing facilities on the Oak Ridge Reservation (*i.e.*, Y-12, K-25, and S-50). This section characterizes key release sources associated with each facility, summarizes the approaches used by the project team to evaluate the quality of airborne effluent monitoring data, and presents independently reconstructed estimates of uranium releases from the ORR for the time period 1944 through 1995.

2.1 Air Releases from the Y-12 Complex

Preliminary investigations of the Oak Ridge Health Studies indicated that, while there were routine uranium releases to the waters of East Fork Poplar Creek, associated exposures to off-site populations were likely minimized by predicted low concentrations of uranium in surface water and limited human use of the Creek. A significant portion of the Task 6 investigation focused on describing key uranium production operations, plausible release mechanisms, effluent monitoring data, and amounts of uranium compounds released to the air during historical Y-12 operations. This section presents descriptions and discussions of:

- key uranium air release sources associated with the Y-12 site;
- historical monitoring methods and practices used by Y-12 contractors to measure the amounts of airborne uranium released to the off-site environment;
- approaches used by the Task 6 project team to evaluate the quality of historical air monitoring data for uranium concentrations in exhaust stacks and indoor air;
- the approach used by the project team to estimate monitored and unmonitored airborne uranium releases from Y-12; and
- results of the process to derive improved annual uranium release estimates for the Y-12 site.

2.1.1 Y-12 Release Sources and Monitoring Practices

Historical uranium process operations housed in a variety of buildings at the Y-12 site routinely released uranium to the outdoor air or are known to have been sources of accidental releases. Included in this section are descriptions of these release sources and historical effluent monitoring practices used by Y-12 contractors to estimate uranium releases. The approach used by the Task 6 project team to evaluate the quality of effluent monitoring data and estimate historical uranium air releases are also described.

2.1.1.1 Y-12 Air Release Sources

Uranium operations at Y-12 were usually carried out in ventilated enclosures (*e.g.*, gloves boxes) and, in many cases as Y-12 developed into a nuclear weapon component manufacturing facility in the 1950s, exhausted air was passed through dust collectors (air filters) or chemical scrubbers before the air was released to the atmosphere[1] (Patton et al. 1963; McRee et al. 1965; Compere 1991). During the years of uranium enrichment (1943 through 1947) uranium was released to the air as a result of:

- *Chemical conversion of uranium oxide to uranium tetrachloride*– Large quantities of carbon tetrachloride (CCl_4) and thousands of kilograms of natural uranium oxides (uranium dioxide (UO_2) "brown oxide", uranium trioxide (UO_3) "orange salt", and (U_3O_8) were used to produce uranium tetrachloride (UCl_4) feed material for the electromagnetic separation units. These operations were primarily housed in Buildings 9202 and 9203 and resulted in significant releases of uranium to the outdoor air. Physical handling and chemical mixing of uranium took place in large versions of laboratory-type hoods that exhausted uranium-contaminated air through unfiltered vents and exhaust stacks[1] (Griffith 1957; Compere et al. 1991). Uranium that was not contained by the hoods often became suspended in general building air and was typically released to the outside through building vents. For a limited period in 1945, Y-12 received partially enriched uranium hexafluoride (UF_6) gas from K-25 and S-50 as additional feed material for electromagnetic enrichment.

- *Electromagnetic separation of uranium*– Airborne uranium releases during electromagnetic enrichment were fairly small because the calutrons were operated under vacuum (Griffith 1957; Compere et al.1991). These releases were generally small in comparison to the feed preparation and depleted uranium recovery operations. When failures occurred and uranium escaped from the calutrons, subsequent releases contained a variety of enrichment levels and occurred mostly through general air vents in the Alpha and Beta Buildings (9201-1, 9201-2, 9201-3, 9201-4, 9201-5, 9204-1, 9204-2, 9204-3, and 9204-4).

- *Uranium recovery and recycle*– After each calutron enrichment run, natural, enriched, and depleted uranium were recovered from the calutron units using scraping and brushing tools and nitric acid solutions. If necessary, uranium solutions were then prepared for further enrichment ("recycle" through another calutron separation). Recovery took place in laboratory exhaust hoods or in open rooms, where uranium was released to general building air. These operations were housed in Buildings 9202, 9203, and 9206. The various forms of uranium that were released to the air during these operations passed filtered and unfiltered to the outside through elevated exhaust stacks and vents (Rutherford 1956; Griffith 1957; Emch 1971; Compere et al. 1991; Owings

[1]Personal communication between John M. Googin (former Y-12 worker) and the Task 6 project team on February 26, 1993.

1995). Although on a smaller scale, releases from these operations also occurred through vents in the Alpha and Beta electromagnetic process buildings.

From 1947 through 1951, Y-12 carried out an extensive recovery program to retrieve natural and depleted uranium from miscellaneous parts and equipment associated with the electromagnetic enrichment operations (Googin 1993). For example, large strips and plates made of carbon and contaminated with uranium were fed through a "crusher" and a "pulverizer" to reduce their size. Small pieces were then loaded in muffle furnaces and burned (Uffelman 1948a-d). The resultant ash was retrieved and dissolved in an acetic/nitric acid solution to recover the uranium. These operations resulted in considerable levels of uranium dust being suspended in local air (exhaust hoods) and general building air (Smith et al. 1946; Compere 1991). Similar operations continued during Y-12's weapon component manufacturing years (1952-1995).[1]

Later on during the years of nuclear weapon component manufacturing at Y-12 (approximately 1952 to 1990s), uranium in various chemical forms was chemically processed, purified, and converted to metal form for production of nuclear weapon parts. The main processes were housed in Buildings 9201-5, 9204-2E, 9204-4, 9206, 9212, 9215, and 9998. Chemical forms associated enriched uranium operations included (Struxness 1951a; Griffith 1957; Patton et al. 1963):

- uranium hexafluoride (UF_6) and uranyl fluoride (UO_2F_2) associated with chemical reactor operations for converting UF_6 to uranium tetrafluoride (UF_4). Effluents from these processes were treated with cold traps to minimize releases of UF_6 and UO_2F_2;
- uranium dioxide (UO_2), uranium trioxide (UO_3), and uranium tetrafluoride (UF_4) associated with metal conversion and forming operations. Effluents associated with these operations were typically treated with roughing and high efficiency particulate air (HEPA) filters; and
- uranyl nitrate hexahydrate ($UO_2(NO_3)_2\,6H_20$) and numerous other forms associated with chemical recovery and purification operations. These effluents were treated with scrubbers and particulate filters.

Natural and depleted uranium processed from 1952 to 1995 were handled almost exclusively in metal forming and machining operations (Patton et al. 1963). Main material handling processes for these operations were housed in Buildings 9201-5, 9204-4, 9202, 9203, 9211,9212, and 9998. Chemical forms included uranium dioxide (UO_2), uranium trioxide (UO_3), and uranium metal (which usually oxidized rather rapidly). Most natural and depleted uranium in airborne effluents were released mostly unfiltered and unmonitored[1] (Owings 1986).

Once in metal form, uranium was forged or cast, cut to approximate sizes, rolled and pressed into rough shapes, machined on cutting lathes, and passed through or along sanding and polishing machines. Similar

[1]Personal communication between Charles M. ("Hap") West (Former Y-12 worker) and the Task 6 project team, October 29, 1992.

to the early operations of 1944 to 1951, these processes released uranium to building air or to ventilation ducts and exhaust stacks. The uranium-laden air was either passed unfiltered to outdoor air or passed through one or more filters prior to release. Based on review of production records, effluent monitoring data, and information gathered from interviews with active and retired workers, Task 6 personnel focused on the Y-12 buildings listed below as the key sources of atmospheric uranium releases for the period 1944 to 1995. The estimated contributions from these buildings to total Y-12 uranium air releases are also indicated below.

- Buildings 9206, 9212, and 9215 contributed over 90% of enriched uranium air releases;
- Buildings 9202, 9203, and 9211 accounted for about 70% of natural uranium air releases;
- The "Alpha" buildings (9201-1, 9201-2, 9201-3, 9201-4, and 9201-5) and "Beta" buildings (9204-1, 9204-2, 9204-3, and 9204-4) added about 30% of natural uranium air releases; and
- Buildings 9201-5, 9204-4, 9211, 9212, and 9998 contributed over 95% of depleted uranium air releases.

Appendix A can be referred to for details regarding the locations of these key buildings, summaries of the uranium processes that occurred in each building, and how, for some buildings, processes and even basic missions changed significantly over time. Appendix C also presents specific information on monitored and unmonitored uranium release sources at Y-12 (such as stack locations and flow rates).

As previously stated, uranium releases from Y-12 included enriched uranium, depleted uranium, and natural uranium. These releases consisted primarily of uranium particulates, fumes[1], and vapors. Most uranium compounds handled at Y-12 would react with moisture in air to form highly insoluble oxide. Highly insoluble uranium oxide was reported to be the dominant chemical form released in airborne effluents from Y-12. This material exhibits a slow clearance rate from the body if inhaled, and therefore results in the highest radiation dose for inhalation of any chemical form of uranium. A key physical characteristic in accurate air sampling, atmospheric dispersion modeling, and assessment of inhalation of contaminated air is the particle size distribution of the contaminant. Studies have been conducted at Y-12 to characterize uranium particle sizes in effluents. These studies indicated that, under normal conditions, uranium oxide particles were predominantly composed of small particles with typical mean diameters of 0.05 to 5 micrometers (millionths of a meter, Fm) (Struxness 1952; Struxness 1953; Pflasterer 1953). Based on review of this information, one micrometer diameter uranium oxide particulates was the form of uranium assumed to have been released for the purposes of the Task 6 screening assessment that is presented in Section 4 of this report.

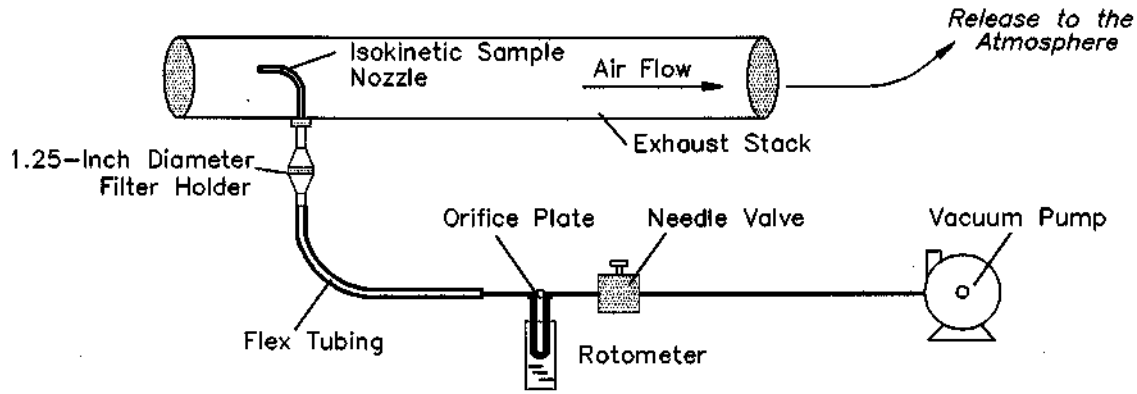
[1]Minute solid particles formed by heating of the metal.

2.1.1.2 Descriptions of Y-12 Air Effluent Monitoring Practices

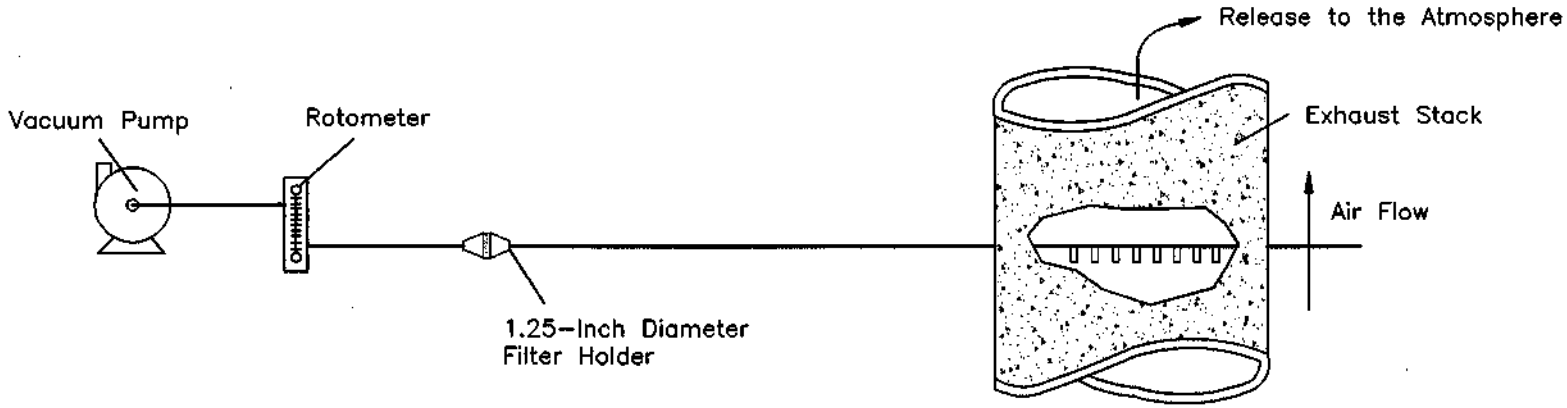
During the Manhattan Project (1943-1947), Y-12 conducted indoor air monitoring for purposes of assessing worker exposures to airborne uranium and determining the amount of uranium being lost to the atmosphere (Smith et al. 1945). Uranium concentrations in indoor air were determined through the collection of periodic grab (short term) air samples. Measurement techniques used in obtaining grab samples were crude by today's standards, however, these did provide quantitative estimates of the relative amounts of uranium that were present in the production areas that may have been lost through general building ventilation and exhaust hoods. Air sampling equipment commonly used at Y-12 during this period was developed by the University of Chicago and consisted of a high-efficiency asbestos-based filter paper through which air was drawn to collect airborne particles. The filter paper was manufactured by the Hollingsworth and Vose Company and was known as the HV No. 9081 or the HV No. 8912. The paper was formed into a cylinder, supported by a special "bird cage," and placed in the sample apparatus, commonly referred to as filter tubes. Flowmeters were used to set the proper sampling flow rate. The rest of the sampling equipment consisted of a holder and plugs for the filter tube, a vapor removing canister, a source of suction (Filter Queen Vacuum Cleaner), and a bleed valve for controlling air flow (Berggren 1947).

The filter paper tubes were then measured for gross alpha radioactivity (counts per minute) in Building 9203. A background (blank) filter tube was also counted and subtracted from the sample count for determining the net amount of Y-12 uranium on the sample. Uranium releases were reported by converting the net counts per minute to net activity and then to mass (e.g., grams) by applying the specific alpha activity in a sample. Samples usually had the same specific activity as the uranium being processed in the sampling area. When the uranium isotopic concentration was different or unknown, Y-12 then collected samples of the process uranium and performed a specific alpha activity analysis using measurement techniques such as fluorometry.

Starting in mid 1950s, operations that handled enriched uranium were increasingly measured for loss of uranium through ventilation systems and exhaust stacks through the use of continuous exhaust stack air samplers (Schappel 1961; Googin 1993). Continuous sampling was accomplished using sampling probes mounted inside exhaust stacks and ventilation ducts. Air sampling probes were used to collect representative (isokinetic) air samples from air streams inside the stacks and ducts in order to quantify the uranium that was routinely exhausted to the atmosphere. Air samples were drawn from exhaust air by isokinetic probes attached to vacuum pumps, and passed through sampling lines to one-inch diameter filter papers loaded inside holders located on the outside of exhaust stacks or ducts. Sample line lengths ranged from just a few inches up to several feet. Schematics of commonly used Y-12 stack sampling systems are shown in Figure 2-1.



Isokinetic Stack Sampling System for Measuring Uranium in Smaller Diameter Exhaust Stacks



Multiprobe Stack Sampling System for Measuring Uranium in Large Diameter Exhaust Stacks

ChemRisk
A Division of McLaren/Hart

Filename: R:\Oakridge\Comp.dwg

FIGURE 2-1

Schematic Diagram for Uranium Stack Particle Sampling Systems Used at Y-12

Air samples were collected continuously, with sampling durations usually ranging from one to three days. Once retrieved from its holder, each filter was sent to the radioactive counting laboratory (Building 9995), loaded into an alpha scintillation or gas proportional radiation counting instrument, and analyzed for alpha radioactivity. The amount of alpha radioactivity present on the filter was then converted to the amount of uranium on the sample based on a predetermined ^{235}U enrichment level.

Each sample was typically held for 24 to 48 hours prior to counting, to allow for decay of natural radioactive background that was also present on the filter paper, such as from radon (^{222}Rn; 3.82 day radioactive half life) and thoron (^{220}Rn; 55.6 second radioactive half life) and their associated radioactive decay progeny[1] (*e.g.*, ^{214}Bi; 19.9 minute radioactive half life) (McRee et al. 1965; Kocher 1981). This holding period allowed the alpha measurements to more precisely determine the uranium concentration in airborne effluents.

In some operations, excessive sampling equipment failure occurred due to the highly acidic nature of sampled gas streams. In these cases, such as in Building 9212 chemical operations, Y-12 personnel collected periodic grab samples using portable air samplers[2] (Struxness 1952; Sanders 1992). In addition, airborne releases associated with depleted and natural uranium operations were monitored only on a periodic basis for limited periods of time using grab samples.

Overall, the methods and approaches used by Y-12 to monitor uranium effluents were usually accepted practices for the time period and provide adequate data for present-day estimates of historical releases. Based on the Task 6 investigation, it was concluded that the largest, single source of uncertainty in estimating uranium releases are unmonitored releases that occurred from 1943 through the 1970s.

2.1.2 Y-12 Air Release Estimates

Estimates of uranium releases for individual exhaust stacks and building vents were tabulated by the project team from original Y-12 documents and included two basic types of release information: (1) reported releases for individual buildings or uranium processes and (2) exhaust stack or indoor air monitoring data and quantities of air exhausted from individual buildings or exhaust stacks. For unmonitored releases or for sampling periods where there was limited data, the project team used uranium production rates or release estimates for preceding or subsequent years for which sampling data were available.

For operating periods for which monitoring data were available, the project team used uranium concentrations determined from air samples in combination with the amount of air exhausted through stacks and building vents to estimate the quantity of uranium routinely or accidental released during a particular sampling period. Basic effluent monitoring data identified by the project team were found in medical physics, health physics, industrial hygiene, and production-related Y-12 reports and on archived electronic

[1]Personal communication between Bill Tucker (Y-12 worker) and the Task 6 team, Oct. 13, 1995.

[2]Personal communication between Jerry Hunt (former Y-12 worker) and the Task 6 team, July 1993.

files. These data consisted of alpha activity measurements for individual air samples and exhaust stack air flow rates for individual stacks and ventilation ducts. Examination of these data by the project team indicated that some of the air sample results may have been corrected for sampling biases, such as particle losses in sampling equipment and alpha particle burial within sample filter paper (Smith et al. 1946; Schappel 1961). For purposes of the Task 6 evaluation, the project team corrected for these potential losses if it was apparent that Y-12 workers had not applied corrections to the monitoring data prior to reporting release estimates. For indoor air monitoring data, correction for sample line losses were not applied to the release estimates.

Task 6 release estimates were then compared to previously reported DOE estimates. If a previously reported release estimate for particular year was found to be larger than the Task 6 estimate, then the release amount was increased to equal the DOE estimate. Based on discussions with Y-12 workers, unmonitored release sources were almost exclusively associated with depleted uranium operations and would account for the majority of the differences between the Task 6 and DOE release estimates[1]. For the purposes of the Task 6 evaluation, the project team assumed the balance of uranium released was depleted uranium. Details of the data used in the Task 6 evaluation of the Y-12 releases is presented in Section 2.1.2 and in Appendix D.

The following sections describe the approaches used by Task 6 project team to quantify historical airborne uranium releases from the Y-12 complex. These discussions are separated into five discrete time periods, namely 1944-1956, 1957-1959 and 1963, 1960-1962, 1964-1988, and 1989-1995.

2.1.2.1 1944 -1956 Airborne Uranium Release Estimates

Release estimates for the period 1944 through 1956 were derived by the project team using air monitoring data and uranium release estimates presented in health physics, industrial hygiene, and production/accountability reports retrieved from Y-12 Central Files and the Y-12 Records Center. Some of these reports provide uranium concentrations measured in indoor air and exhaust stacks and exhaust air flow rates (Smith et al. 1945; Smith et al. 1946; Berggren 1947; Herndon et al. 1947; Morfitt 1947). Other reports used by the project team to estimate historical releases contain only previously determined release estimates without the supporting effluent monitoring data (Griffith 1957).

Using available monitoring data, the project team calculated releases to verify the accuracy of the reported releases. Average uranium air concentrations ($\mu g\ m^{-3}$) were multiplied by exhaust air flow rates ($m^3\ yr^{-1}$) to determined the total amount of kilograms released per year per release point. Annual mass releases were then converted by the project team to the amount of radioactivity released (curies y^{-1}, Ci y^{-1}) based on the estimated ^{235}U enrichment level. The majority of releases that occurred from 1944 to 1956 consisted primarily of natural uranium (0.0057 percent weight ^{234}U; 0.72 percent weight ^{235}U; and 99.28

[1]Personal communication between Edward Owings (former Y-12 worker) and the Task 6 team, July 1997.

percent weight ^{238}U) and depleted uranium (an average of 0.002 percent weight ^{234}U; 0.25 percent weight ^{235}U;and 99.75 percent weight ^{238}U was assumed for the Task 6 assessment). The specific activities of the individual uranium isotopes used in the calculations are 6.29 Ci kg^{-1} for ^{234}U, 2.19×10^{-3} Ci kg^{-1} for ^{235}U and 3.4×10^{-4} for ^{238}U. Other releases that occurred during this time period also contained enriched uranium. Descriptions of the Task 6 approach used to estimate releases for this operating period are presented in Appendix D. The formulas used to derive release estimates for 1944-1956 were:

Mass Release Rate (kg y^{-1}) = (g m^{-3}) (m^3 d^{-1}) (365d y^{-1}) (10^{-3}kg g^{-1}) and

Uranium Isotope Release Rate (Ci y^{-1}) = (kg y^{-1}) (percent weight of isotope) (Ci kg^{-1})[1].

Since the project team did not obtain a complete set of monitoring data for the period 1944 to 1956, reported releases for Buildings 9206 (post 1947), 9211, 9212, and an unspecified Beta building were also used to derive Task 6 release estimates for this time period (Griffith 1957). Reported estimates of total kilograms of uranium released from a particular release source were used by the project team to complete the revised release estimates for 1944 through 1956 (*e.g.*, 10,000 kg of normal to depleted uranium released from Building 9212 from 1953 through 1955). According to the 1957 Griffith report, reported releases were based on available effluent monitoring data, known releases, and production and inventory records. The majority of these releases were reported to have been depleted uranium.[2] Documents that describe additional effluent monitoring data and production and inventory data used by Y-12 to derive their release estimates were not available for the Task 6 evaluation. Due to limited available monitoring data or release estimates for some years, the project team estimated releases by calculating averages based on release estimates and/or production data for the preceding and subsequent years. Calculations used for this portion of the Task 6 assessment are presented in Section D.2 of Appendix D. Further evaluation regarding the accuracy of the DOE/AEC reported Y-12 release estimates is warranted during a future dose reconstruction study of Y-12 uranium. Table D-3 in Section D.3 of Appendix D provides a list of documents that may provide further information to assist in ascertaining the uncertainty in these reported release estimates. These documents were not found during the Task 6 investigation.

2.1.2.2 1957 - 1959 and 1963 Airborne Uranium Release Estimates

Quarterly average total uranium concentrations measured in exhaust stack effluents were used by the project team to estimate air releases for the years 1958, 1959, and 1963. These data were located in Y-12 analytical laboratory documents (Tucker et al. 1996). Reported quarterly averages were determined by Y-12 workers based on daily stack monitoring data. Daily measurement data for these years were not located during the Task 6 investigation, therefore, the project team used the quarterly data for estimating

[1]Percent weights of uranium isotopes (*i.e.*, ^{234}U, ^{235}U, and ^{238}U) are based on enrichment level.

[2]Personal communication between John M. Googin (former Y-12 worker) and the Task 6 team on February 26, 1993.

releases. For 1957, reported monthly measurement data were used for the analysis. The daily or quarterly data consisted of average net alpha activity per unit volume of air expressed as disintegrations per minute per cubic meter of air ($d\ min^{-1}\ m^{-3}$). Net alpha activity concentrations represent the amount of total uranium released in Y-12 airborne effluents. Y-12 determined the net activity by allowing for the decay of short-lived radon and thoron progeny prior to counting the air samples and through the subtraction of long-lived background radiation. These values were then multiplied by reported volumetric air flow rates ($m^3\ qtr^{-1}$) to arrive at monthly, quarterly, and annual uranium release totals. The project team then converted the total alpha activity released to the amount of kilograms and activity per uranium isotope (^{234}U, ^{235}U, and ^{238}U) based on the known ^{235}U enrichment level. Release estimates for this operating period were either enriched uranium (93.5 percent ^{235}U by weight) or depleted uranium with an average ^{235}U weight content of 0.25 percent (Patton 1963; Owings 1986). Additional details regarding the data and calculations used by the project team for this portion of the Task 6 assessment are presented in Sections D.4 and D.5 of Appendix D.

2.1.2.3 1960 - 1962 Airborne Uranium Release Estimates

Monthly stack sampling results presented in Y-12 health physics reports for 1960, 1961, and 1962 were used by the project team to derive enriched and depleted uranium release estimates for these three years. Monthly release totals in units of microcuries (μCi) of total alpha activity are presented in these reports and were used as the basis for the Task 6 release estimates for this operating period. Reported uranium releases per stack are based on daily measurements of effluents collected by continuous or periodic stack samplers. Samples were collected in exhaust stacks down stream of exhaust filters in Buildings 9206, 9212, 9215, and 9998. Daily measurement data for these years were not located during the Task 6 investigation, therefore, the project team used the monthly release estimates for estimating annual releases for the three years. The project team then converted the total alpha activity released to the amount of kilograms and activity per uranium isotope (^{234}U, ^{235}U, and ^{238}U) based on the known ^{235}U enrichment level. Release estimates for this operating period were either enriched uranium (93.5 percent ^{235}U by weight) or depleted uranium with an average ^{235}U weight content of 0.25 percent. Data and calculations used for this portion of the Task 6 assessment are presented in Section D.6 of Appendix D.

2.1.2.4 1964 - 1988 Airborne Uranium Release Estimates

Basic radiation measurement data that represent the amount of radioactivity collected on stack air samples were identified by the project team. These data were found on archived computer tapes and contain basic radiation measurement data (gross alpha count rates, stack flow rates, counter efficiencies, etc.) for individual air samples collected daily in exhaust stacks and ventilation systems from 1964 to 1988. These data were analyzed by the project team and used to calculate atmospheric releases of uranium for 1964 to 1988.

To reconstruct uranium air releases for this operating period, the project team used the radiation measurement results for 177,356 individual air samples collected from 287 stack or ventilation duct

monitoring locations at Y-12 (Garmeson et al. 1996). The data were examined and corrected for errors, such as incorrect reporting of exhaust stack air flow rates and omission of appropriate correction factors to adjust the data for biases caused by sample line and alpha burial losses. Over 47,000 errors were corrected using other information collected during the investigation such as reported stack flow rates taken from Y-12 health physics logbooks (Rutherford 1956; Schappel 1961; Emch 1970; Emch 1971). This means that approximately 26 percent of the data were found to contain one or more errors and were corrected as part of the Task 6 process to reconstruct uranium release estimates. The stack sampling data used by Task 6 investigators to reconstruct release estimates include the following information (Garmeson et al. 1996):

- Date and frequencies of sampling for each exhaust stack;
- Sample location (stack or vent location);
- Type of uranium sampled, in terms of ^{235}U enrichment, selected from four categories:

  highly enriched. . . . . 93.5 percent or greater ^{235}U content
  intermediate enriched. . . . . 70 percent ^{235}U content assumed for Task 6 assessment
  depleted. . . . . 0.25 percent ^{235}U content assumed for Task 6 assessment

- Volumetric air flow rate in the sampling line;
- Air sampling duration (usually 1 to 3 days);
- Volumetric air flow rates periodically measured in exhaust ducts and stacks and reported in health physics and operations logbooks (Rutherford 1956; Emch 1971);
- Net alpha activity measured on filter paper to determine uranium content;
- Counting time used to measure alpha activity on filter paper;
- Alpha counting efficiencies (calibration factors for alpha scintillation and gas proportional radiation counters);
- Correction factor of 0.3 for sample loss due to absorption of alpha particles in filter paper (also known as burial loss)[1] (Smith et al. 1945; Struxness 1951);
- Correction factor of 0.25 to account for sample line losses due to particle deposition and impaction in the tubing or piping used to draw the samples (Schappel 1961); and
- Measured collection efficiencies of filter papers (usually reported to be between 98 and 100 percent) (Struxness 1951a; Schappel 1961).

[1]Personal communication between Bill Tucker and the Task 6 project team on October 13, 1995. Personal communication between Bob Rutherford (Y-12 fomer Y-12 worker) and the Task 6 project team on November 18, 1992. Personal communication between C. M. "Hap" West (retired Y-12 worker) and the Task 6 project team on April 30, 1996.

Using the corrected measurement data, uranium release estimates for 1964 to 1988 were generated by the project team. Detailed descriptions of the calculations and methods used by the project team to derive release estimates from these sample data are included in Section D.7 of Appendix D.

2.1.2.5 1989 - 1995 Airborne Uranium Release Estimates

The project team decided that it was not appropriate to devote significant Task 6 resources to reconstruction of releases for this period of relatively low releases and modern monitoring practices. DOE and Y-12 reported estimates for 1989 to 1995 were determined to be representative of actual releases, and were used to complete the Task 6 reconstructed air release estimates.

2.1.2.6 Estimates of Unmonitored Releases

For periods when sampling was either not performed or sampling records could not be found, air releases were primarily estimated by the project team using uranium production data or uranium release estimates for preceding or subsequent sampling periods. Uranium releases were estimated using this approach for the following operational periods and release sources:

- Natural uranium releases
  For 1944 and 1945: . . . . Selected releases Alpha, Beta, 9202, 9203, and 9206 Buildings
- Depleted uranium releases
  For 1968, 1972, 1974 - 1987: . . . Selected releases Buildings 9201-5, 9204-4, and 9998
- Enriched uranium releases
  For 1968: . . . . . Selected releases from Buildings 9206, 9212, 9215

For example, monitoring data located for 1944 and 1945 were limited and determined not to be representative of all releases during that time period. To estimate releases for those periods for which monitoring data or reported releases were not found, Task 6 investigators used production data and release estimates for adjacent years. Production data for an unmonitored period was compared to production data for adjacent time periods for which release estimates were available. Release estimates for the unmonitored period were then calculated based on the differences in production data for the two time periods. Estimates of unmonitored or undocumented releases were then added to the total releases presented in Appendix D.

Uncertainties associated with unmonitored estimates were not evaluated and, in some cases, estimates of these releases could not be made due to the limited amount of data. A full accounting of releases would require additional information that describes the air sampling approaches used and the extent to which monitoring data are representative of the unmonitored releases. Information could be sought to assess the uncertainties of release estimates for these unmonitored operations. The project team believes that other records, such as the ones described in Appendix D, may provide further information to estimate the uncertainty in the estimates. The sample documents presented in Appendix D were identified from a bibliography list, but were not located during the Task 6 investigation.

For the remaining operating periods and uranium operations listed above (depleted and enriched releases for the 1960s to the 1990s), the Task 6 project team averaged releases for adjacent years or used DOE reported release estimates to arrive at estimates for unmonitored releases.

The Task 6 uranium air release estimates for 1944 to 1995 are summarized in Figures 2-2, 2-3, and 2-4. Uranium activity amounts for ^{234}U and ^{235}U were combined to add a level of conservatism to the Task 6 screening assessment. This approach is considered reasonable for the assessment since the majority of activity released from 1944 to 1995 is associated with the ^{234}U component, Task 6 release estimates do not include a formal uncertainty analysis, and the dose conversion factor (DCF) for ^{234}U is higher than the DCF for ^{235}U. It would be appropriate to evaluate these uranium isotopes separately during a refined dose assessment such as one associated with a complete dose reconstruction study. The project team's estimates are presented alongside published DOE release estimates in Table 2-1 and Figure 2-5. Details regarding the data and calculations used by Task 6 to estimate uranium releases are given in Appendix D.

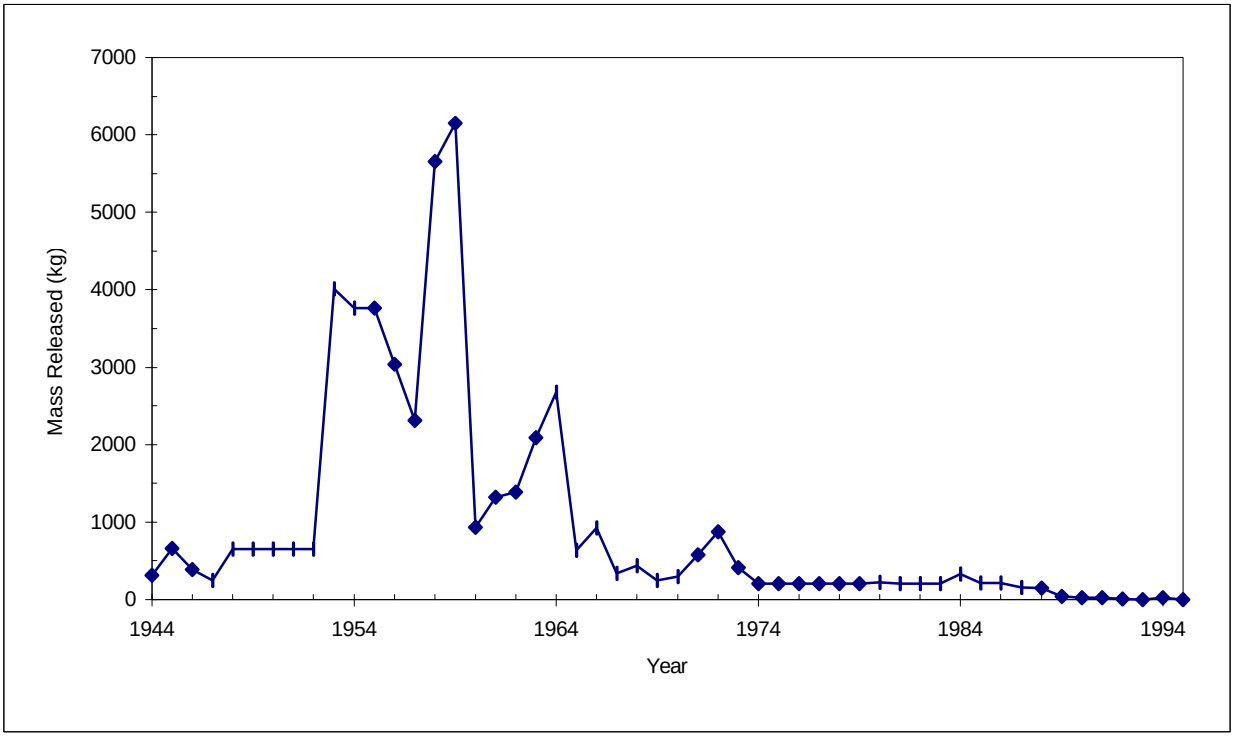


Figure 2-2: Task 6 Estimates of Annual Airborne Uranium Releases from the Y-12 Complex

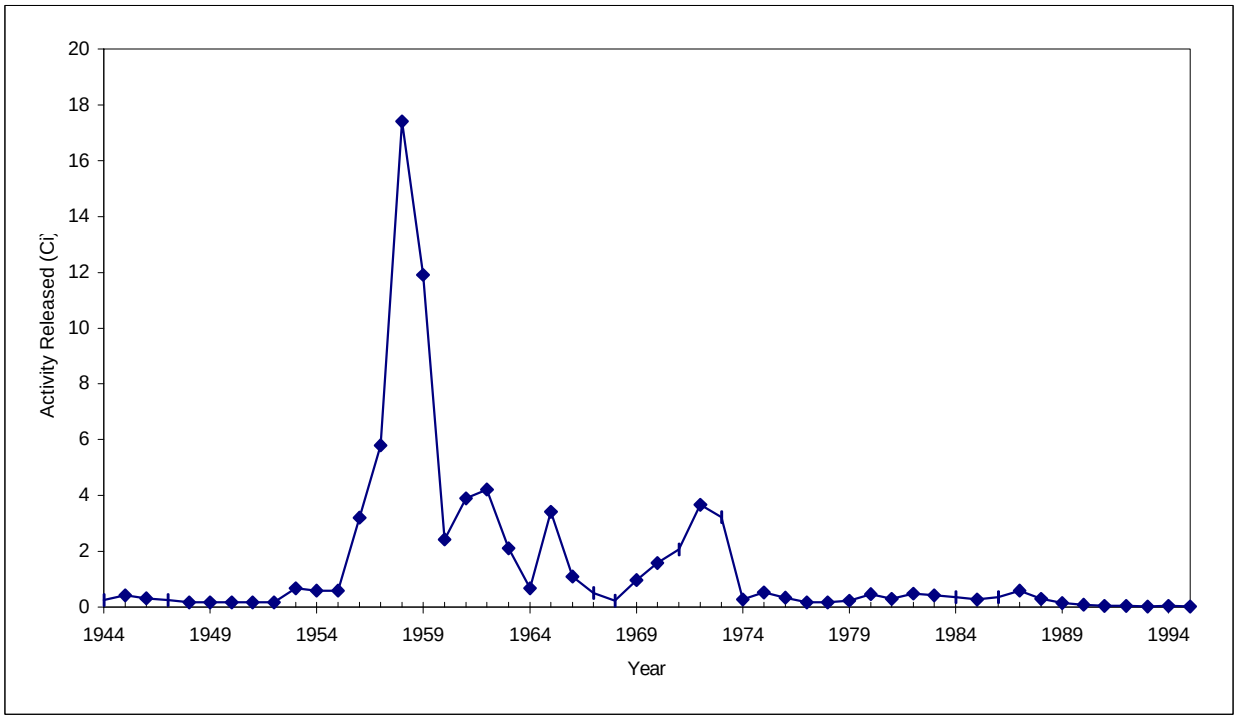


Figure 2-3: Task 6 Estimates of Annual Airborne $^{234/235}$U Releases from the Y-12 Complex

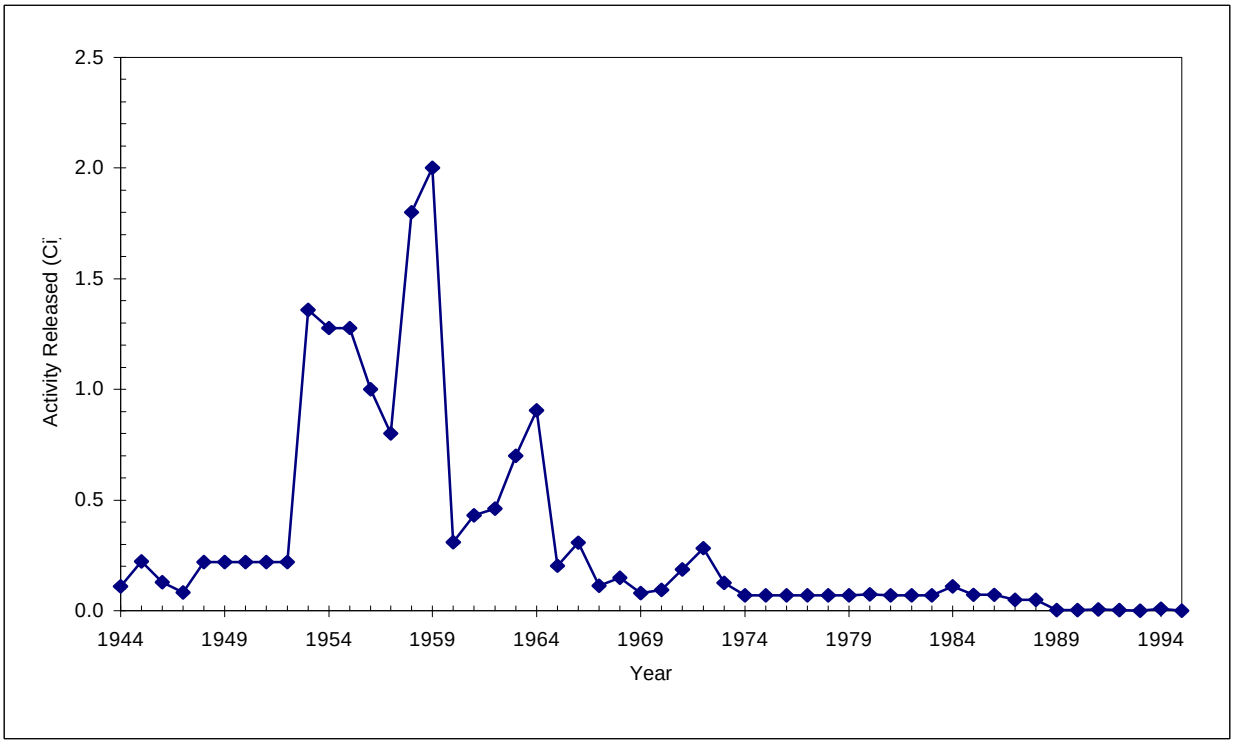


Figure 2-4: Task 6 Estimates of Annual Airborne ^{238}U Releases from the Y-12 Complex

Table 2-1: Y-12 Airborne Uranium Release Estimates[†]

Year	Task 6 Estimate (kg)	DOE Estimate (kg)
1944	310	55
1945	670	102
1946	390	102
1947	250	55
1948	650	0
1949	650	0
1950	650	0
1951	650	0
1952	650	0
1953	4000	30
1954	3800	32
1955	3800	32
1956	3000	43
1957	2300	41
1958	5700	41
1959	6200	120
1960	930	99
1961	1300	109
1962	1400	100
1963	2100	103
1964	2700	170
1965	640	281
1966	920	212
1967	340	212
1968	440	211
1969	250	223
1970	300	259
1971	580	290
1972	870	222
1973	410	206
1974	210	207
1975	210	209
1976	210	207
1977	210	206
1978	210	205
1979	210	206
1980	220	218
1981	210	207
1982	210	207
1983	210	208
1984	330	329
1985	210	210
1986	210	211
1987	150	116
1988	150	116
1989*		44
1990*		21
1991*		21
1992*		7
1993*		3
1994*		24
1995*		2
TOTAL	50,000	6,535

* Values for these years were based on releases reported by DOE. Release estimates for these late years were not independently reconstructed by the project team.

[†] DOE Estimates for years 1944 to 1988 compiled from USDOE 1988; estimates for years 1989 to 1995 were from LMES 1996. Task 6 estimates are rounded to two significant figures.

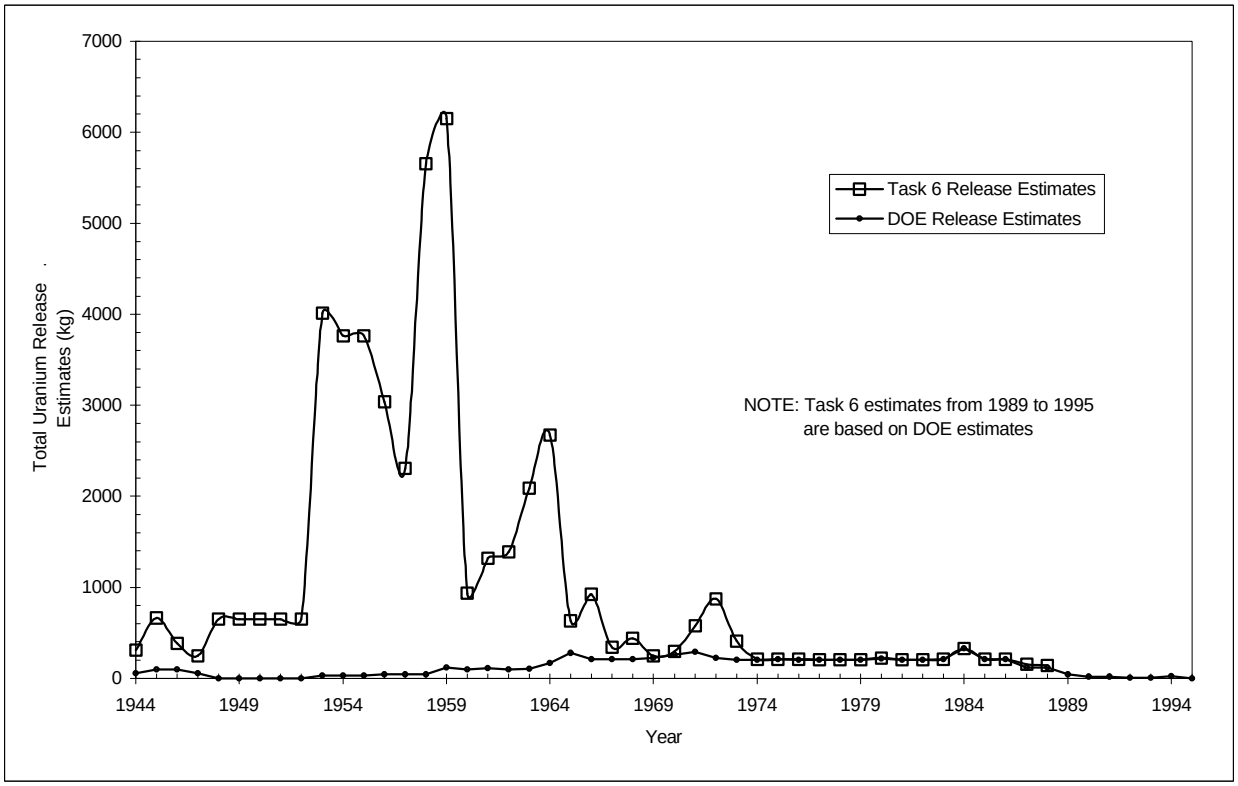


Figure 2-5: Task 6 and USDOE Estimates of Annual Airborne Uranium Releases from the Y-12 Complex

2.2 Air Releases from the K-25 Complex

This section describes the methods used by the project team to estimate airborne uranium releases from the K-25 complex for the period 1944 through 1995. Because the K-25 site did not monitor most uranium releases, the principal method used to quantify historical uranium releases was to identify and retrieve pertinent historical records and to compile a database of release data using the information obtained. As much information as possible about each release was gathered. Releases were categorized by their date of occurrence and amount of release as well as other information that allowed the releases to be classed according to release pathway or location.

The project team's release estimate database is a Microsoft® Excel™ workbook containing many spreadsheets that detail the construction of the uranium release history from 1945 to 1995. References are given for all data contained in the database. Air release estimates are presented as totals for each calendar year. These totals are compared against those from similar assessments performed by DOE/AEC/K-25 staff. In cases where the totals calculated by the project team for a given year were less than those from the DOE/AEC/K-25 assessment, the value from the DOE/AEC/K-25 assessment was used to establish the total for that year. The sum of all air releases calculated by the project team over all years was then

compared to that from the DOE/AEC/K-25 assessments. The total calculated during the Task 6 investigation is 16,336 kilograms of uranium released. The historical release assessments performed by DOE/AEC/K-25 staff for the same period amount to 10,713 kilograms, nearly 6,000 kilograms less than the Task 6 estimates. The project team was unable to establish the magnitude of releases for nearly one third of the reported release events that occurred during past K-25 operations (1944 to 1995) because essential data (e.g., mass of material released) were not available to the project team. It is likely that actual releases are substantially higher than the estimates presented in this report. In addition, these totals do not include the majority of releases that occurred at the S-50 liquid thermal diffusion plant. Releases from this facility are known to have been very large, but only limited historical information was available to the project team.

The majority of the data used by Task 6 to estimate K-25 airborne releases came from accountability records. These records provide specific information regarding uranium releases such as when, where, why, and how uranium was released from K-25. Such records include routine accountability reports, reports describing accidental releases, and effluent and release reports for specific buildings (rather than for the site as a whole). In addition to these accountability documents, environmental monitoring reports were also used to augment the information in the release database.

It should be noted that only quantified data were included in the total release sums, even though there are many instances where unquantified releases are known to have occurred. Known releases for which no quantitative data were available (e.g., release reports where no estimations were given for the quantity released) are not accounted for in the Task 6 release estimates. Hence, the release database is known to underestimate the amount of uranium actually released from the K-25 site. Despite this, total uranium release estimates compiled by the project team are still greater than estimates reported by DOE/AEC/K-25 by nearly 6,000 kilograms. In alternate estimations of releases from the K-25 site performed earlier in the project, the available release data were fit using probability distributions in an effort to "fill in the gaps" where releases were known to be understated or undocumented. This approach was not used in this present investigation due to concerns expressed by reviewers and would require additional source term information to validate assumptions used in the probability analysis.

One source of chronic airborne uranium releases to the environment were the purge cascades, which were facilities within the K-25 and K-27 diffusion plants used to separate light diluents (such as air that bled into the system) from the UF_6 (see Appendix F for details). While it was thought by the K-25 staff to be a major source of releases for the site, the Task 6 assessment found this not to be the case. Release estimates for the purge cascades are discussed in Section 2.2.3. The overall process used by the project team to independently develop airborne release estimates for K-25 is as follows:

- Compiled data on releases tracked by the Uranium Accountability Division for both the K-25 and S-50 plants

- Developed release estimates for a series of UF_6 cylinder fire tests

- Compiled and reviewed Annual Environmental Monitoring Report release estimates
- Performed release calculations for the purge cascade and assessed significance
- Compared the total release estimates to officially-reported DOE/AEC/K-25 plant releases

The sections that follow describe these five steps, provide estimates of the total masses and activities of uranium released from the K-25/S-50 complex, and compare these estimates to previous release estimates reported by DOE/AEC/K-25. Section 2.2.5 summarizes future refinements to the K-25 release estimations that were identified by the project team as a result of their assessments.

2.2.1 The Airborne Release Database for 1944 to 1995

The Excel™ workbook developed by the project team primarily functioned as a database of uranium releases from the K-25 site. Release data were obtained from documents retrieved from records centers at the Oak Ridge Reservation (ORR). The documents were mainly accountability records that indicated when, where, why, what and how much material containing uranium was released. Release data were entered into the database by release date. In cases where data were given for a specified period of time (such as monthly, quarterly or annual totals), the date assigned was the first day of the first month in the period.

After the database had been compiled, the uranium release data (in terms of kilograms of total uranium) were summed for each calendar year. These sums were then compared with those from similar assessments performed by DOE/AEC/K-25 staff (Lay and Rogers 1986) (Rogers 1985). In cases where the Task 6 estimates from the current effort were less than those from the DOE/AEC/K-25 assessments, the total release assigned for that year was taken from the DOE/AEC/K-25 evaluation. This was done because it was assumed that the DOE/AEC/K-25 assessments have a more complete data set available for those time periods. Subsequently, the totals for each calendar year were summed over all years and compared to the values reported by DOE/AEC/K-25.

The majority of the records in the database came from the K-25 Uranium Accountability Group, which was charged with tracking uranium as it moved throughout the plant to prevent diversion, theft or excessive losses. This included tracking any accidental or chronic environmental releases. The environmental releases were reported by shift supervisors in Material Release Reports. Each report contained a description of the incident, the date and location of the incident, the personnel involved in the incident, and either the duration of the release or the quantity of material released. As these reports and similar release information were gathered by the project team, data were entered into the database. The database entries included the date of the incident, the quantity and enrichment level of the material (if known), the location of the incident, and a description of the incident. The database currently contains over 1200 entries. The accountability information in the database includes:

- Accidental releases
- Purge cascade monitoring data for 1945, 1946, 1953-1955, 1961, 1969, 1976-1978, 1980
- Periodic effluent monitoring data for K-1131, K-1420, and K-1401

Other sources of information in the database are environmental monitoring reports and releases established for the cylinder fire tests conducted in 1965. The cylinder fire tests were destructive tests carried out at the K-25 rifle range to establish the failure limits for UF_6 cylinders involved in transportation accidents. Specifically, the tests were performed to determine how long the cylinders could withstand being incinerated in an accident involving a fire. These studies were carried out by lighting a fire underneath full or partially-filled UF_6 cylinders and observing the results. In total, the tests released 277 kilograms of 0.22 percent enriched UF_6 (Mallett 1966), equating to 188 kg of uranium. Table 2-2 presents the dates and amounts of material released during each test. The project team reviewed the available information concerning the cylinder tests, and believes that the reported release totals are adequate for use in the Task 6 screening. $^{234/235}U$ refers to the sum for these two nuclides.

Table 2-2: Uranium Release Estimates for UF_6 Cylinder Fire Tests

Date of Test	Uranium (kg)	$^{234/235}U$ (Ci)	^{238}U (Ci)
October 4, 1965	3	4.5×10^{-4}	1.0×10^{-3}
October 5, 1965	17	2.5×10^{-3}	5.7×10^{-3}
October 7, 1965	76	1.1×10^{-2}	2.6×10^{-2}
October 14, 1965	16	2.4×10^{-3}	5.5×10^{-3}
October 29, 1965	75	1.1×10^{-2}	2.5×10^{-2}

The K-25 airborne release database was an Excel™ workbook consisting of ten spreadsheets. The ten spreadsheets are titled: 1) *Atmospheric Release*, 2) *Atm. Yearly Release*, 3) *Cylinder Fire Test*, 4) *Environment*, 5) *Environment 2* 6) *10% Diff*, 7) *Uranium*, 8) *New Data 10-31*-96, 9) *New Data 8-29-96* and 10) *New Data 11-6-97*. Each sheet is described in the text that follows.

The spreadsheet *Atmospheric Release* contains a chronological listing of releases of uranium for the K-25 site that was established from the initial, large-scale review of accountability records. Releases are classified by their location, total mass of uranium, ^{238}U mass, ^{235}U mass, weight percents of ^{235}U, total activity (in curies) and release pathways. Descriptive notes and references are provided with the release estimates. Releases were assessed into several release pathways. The ESA pathway was used to describe releases from Equipment to Stacks or vents and thus to the Atmosphere. Other pathway categories are EIVA,

which describes releases from process equipment to indoor air to the atmosphere via building ventilation. CA describes outdoor releases from cylinders directly to the atmosphere. CISA describes indoor releases from cylinders to the atmosphere through building ventilation. This spreadsheet is presented in Appendix E along with the other spreadsheets in the database documenting release information obtained from accountability records. The *Atmospheric Release* sheet contains 960 data records.

The worksheet *Atm. Yearly Release* gives the total yearly release amounts for 1945 to 1995 in kilograms of total uranium, curies of total uranium, kilograms of ^{238}U, kilograms of ^{235}U, and curies of ^{238}U, ^{235}U, and ^{234}U. Cumulative totals are also given. Entries for a particular year are the sums of many releases. The releases listed in *Atmospheric Release* were summed for each individual year. To these sums were added contributions from *Environment, Environment* 2, 10*% Diff, New Data 10-31-96, New Data 8-29-96* and *New Data 11-6-97*, as appropriate. The sheet *Atm. Yearly Release* represents the results of the project team's effort to estimate the airborne uranium emissions from the K-25 complex and is presented as Table 2-5 in Section 2.2.4.

The next sheet, *Cylinder Fire Test*, records the releases of UF_6 that occurred in October 1965 at the K-25 Rifle Range as a part of the UF_6 cylinder test and development program. These releases were regarded differently than releases associated with normal production, since they were not considered as material losses, but rather as an approved use, analogous to material processed. Thus, these releases would not have been accounted for in the release estimations performed by DOE/AEC/K-25, since these estimates were based on material loss reports. This is an example of a class of atmospheric release included in the project team estimates that were not included in previously reported estimates.

The sheet *Environment* gives the estimated atmospheric discharges in curies of uranium for the years 1973 to 1982. The discharges were taken from Environmental Monitoring Reports for the Oak Ridge Facilities for the years 1973 to 1982 inclusive (US AEC 1973) (US ERDA 1974-1976) (US DOE 1977-1982). The information in these reports were estimates of uranium released from all Oak Ridge Facilities. It was conservatively assumed that all releases were from K-25 operations since there was no way to separate the contributions from all facilities. The curies of uranium were converted into curies and grams of ^{238}U and ^{235}U using representative enrichments for each year (see below). These amounts were then compared to the amounts that had been determined for the corresponding years from the review of historical records. Where the difference between the amount from the environmental report and the amount from records review was positive for a particular year (*i.e.*, the amount from the environmental report was larger), it was assumed that information was missing from the release history and the difference was therefore added to the Task 6 estimates. This practice likely overstated the releases from K-25 to a small extent, though the total for all of the affected years amounts to less than 5% of the total release estimate for 1944-95.

In *Environment* it was necessary to have an enrichment level in order to convert curies to grams. However, the environmental reports did not give any information regarding enrichment levels. Thus, for those years where there was a positive difference between the environmental report data and the release estimation from the records review, the release data from the review were used to establish a representative

enrichment level. This was done by summing the ^{235}U mass and the total uranium mass for all of the release data for a given year. The total ^{235}U mass was then divided by the total uranium mass to get a representative enrichment level. These enrichment values were then used to establish the ^{235}U and ^{238}U mass releases for each year from the environment data, with the yearly release estimates from the records review subsequently reconciled with these values in accordance with the assumption that all of the uranium came from K-25.

The sheet *Environment 2* contains the environmental monitoring data for 1986 to 1995. The data were provided in terms of total curies and total mass of uranium. Thus, to arrive at a breakdown of kilograms and curies for the individual radionuclides (^{238}U, ^{235}U, and ^{234}U), it was necessary to determine the enrichment level. This was accomplished by using the following numerical expression for alpha specific activity as a function of ^{235}U enrichment by percent weight (Rich et al. 1988):

$$Specific\ Activity = 1\times10^{-6}(0.4+0.38E+0.0034E^{2})\ curies/gram$$

where E is the ^{235}U enrichment in percent.

For each year, the ratio of the activity to the mass was used to define a specific activity to enable solving for E, the percent weight of ^{235}U. Once the amount of ^{235}U was determined, the corresponding amounts of ^{234}U and ^{238}U were computed. Graphical representation of this approach is shown in Figures F-3 and F-4 of Appendix F. As for the earlier environmental data contained in the *Environment* spreadsheet, the resulting enrichment level was an expression of the average enrichment for a given year. One particular year, 1989, had a calculated enrichment that was negative. This implied that the release data for that year were inconsistent. Since only a small amount of uranium was reported that year, namely 1.11 kg, a natural ^{235}U enrichment of 0.72% was assumed. For such a small release amount, the assumption had a negligible effect on the site cumulative release estimate, but the assumption was the determining factor for that year since the environmental monitoring data was the only release information available. This was the case for 1986 to 1995, with exceptions for 1988 and 1993, for which additional release data were located.

The sheets *New Data 10-31-96*, *New Data 8-29-96* and *New Data 11-6-97* contain release data identified after the initial, large-scale records review was completed. Assumptions were employed when adding some of these new data into the annual release totals. In the *New Data 10-31-96* sheet, the uranium released in 1958 and 1959 was assumed to have been natural with a ^{235}U enrichment of 0.72%. This assumption was based on the known operations at the K-1401 and K-1413 facilities. Likewise, the release data for 1988 in this sheet were also assumed to have had an enrichment of 0.72%. However, in this case the choice of enrichment level was more arbitrary, as the project team did not have information regarding where these materials were processed. A ^{235}U enrichment level was assigned to avoid having zero values in the database for the ^{238}U and ^{235}U masses and their associated activities. This assumption has negligible impact on the total mass of uranium asserted to have been released in 1988.

In the *New Data 11-6-97* sheet, the activity data by isotope from the effluent release reports for 1993 and 1994 were converted to mass using the specific activities for the three uranium isotopes. The values used were 3.4×10^{-7} Ci g^{-1} for ^{238}U, 2.19×10^{-6} Ci g^{-1} for ^{235}U and 6.29×10^{-3} Ci g^{-1} for ^{234}U. Enrichments were then established by simply taking the ratio of the ^{235}U mass to the total mass. For the S-50 releases in 1944 and 1945, natural enrichment was assumed given these releases were generally associated with feed material and that the S-50 plant achieved only slight enrichment.

The sheet *Uranium* gives physical data for the element uranium and its isotopes. As necessary, these data were used to calculate grams and curies.

2.2.2 The S-50 Liquid Thermal Diffusion Plant

The S-50 plant, also called the liquid thermal diffusion plant, was built on about 37 acres of land adjacent to the K-25 Power House. Construction began on June 6, 1944 and took 75 days to complete. Partial operations commenced on September 17, 1944 while construction of the other buildings at the site was still being completed (Fox 1945). The plant was operated for nearly 12 months prior to shut down on September 9, 1945. The buildings were demolished and buried during the following year. Some narratives of the operational history assert 10 months of operation, which presumably reflects the period from first product withdrawal to shutdown.

The intended purpose of the S-50 plant was to produce low-enrichment uranium, initially as a feed material to the Y-12 electromagnetic enrichment process, and then later as a feed for the K-25 gaseous diffusion plant. Operations were terminated after its short operating period, in part due to the rapid growth of the output from the gaseous diffusion plant and perhaps in part due to unsustainable losses suffered during the ten to twelve month operating history. Losses from the S-50 plant are thought to represent a significant fraction of the total uranium releases for the K-25/S-50 complex, and were likely the dominant releases during the war years. These losses have not been included in prior DOE/AEC/K-25 release estimates. Although S-50 was physically located at the K-25 site, it was not considered part of K-25 operations. The S-50 plant is one of the major undocumented (or partially documented) sources of historic uranium releases from the Oak Ridge Reservation.

Releases of uranium from the S-50 plant to the atmosphere would occur from planned routine emissions, unplanned chronic releases, and large episodic events. Examples of routine planned emissions include the practice of conditioning the columns by allowing eight pounds of UF_6 to passivate or react with the tubing surface. Current documentation of K-25 environmental activities describes this process as bizarre (LMES 1995). Following conditioning, the residual UF_6, which might be a large fraction of the UF_6 used, was allowed to vent to the atmosphere. Transfers of UF_6 to and from the process equipment were also problematic. Examples of unplanned chronic releases are piping and connection failures which, given the temperature and pressure of the UF_6, were difficult to arrest. There was a complex piping system interconnecting the 2142 triple nested pipes with water, steam, and UF_6. From various accounts of the process, it appears that failures such as this occurred on a greater than daily frequency, perhaps ranging

up to a dozen times a day. Large episodic events occurred as a result of significant failures that would occur in the process system.

2.2.3 Calculation of Purge Cascade Releases

Historically, the purge cascade was considered the only routinely monitored effluent point at K-25. The purge cascade monitoring was process monitoring, which indirectly measured the uranium released along with the other light gases. The gas was then subject to filtering, which reduced the release relative to the amount measured. Some purge cascade effluent data (1946, 1953 through 1955, 1961, 1969, 1975 through 1978 and 1980) were compiled with the uranium accountability data in the release database. While the 1946, 1953-1955, 1961, 1969, and 1975 release totals were independently reconstructed by Task 6 investigators, the 1976-1978 and 1980 data were located only in summary-level form.

An overview of the purge cascade operation and monitoring is provided in Appendix F. The purge cascade effluent reconstruction was based upon data contained in shift supervisors' daily report logbooks. The logs documented purge gas flow rates and UF_6 concentrations measured in the purge gas before the alumina traps and carbon absorbers. Although data were located for nearly all years of operation, it was not feasible as part of the Task 6 screening evaluation to reconstruct release estimates based on forty years of daily purge logs. In addition, it is important to note that the purge cascade monitoring was done only for process control. The monitoring equipment was used to determine the concentration of UF_6 in the purge stream to optimize operation of the gaseous diffusion cascade, not to measure the uranium being released to the environment. For those reasons, the measurements were taken prior to any effluent treatment or control devices.

Estimates of the purge cascade's contribution to uranium releases at K-25 were based on the project team's reconstruction of releases from purge log data for five time periods: December 1945 through December 1946, 1953 through 1955, 1961, 1969, and 1975. These time periods were selected because they represented four distinctive periods of K-25 site operations:

- The late 1940s represented the startup phase, when cascade equipment was coming into operation. Design changes, production improvements, and problem solving were widespread as enrichment capacity grew to around 93 percent ^{235}U by weight.

- The 1950s and early 1960s represented high production for high-enrichment uranium. During this time, K-25 power requirements heightened as the Cold War push to produce weapons-grade uranium and highly-enriched uranium for the naval propulsion program peaked.

- In the late 1960s, production changed from high enrichment for weapons and naval reactors to low enrichment (around 3.5 percent ^{235}U by weight) for the commercial nuclear power industry.

- In the mid-1970s, after USEPA air release regulations were introduced, new trapping and monitoring systems were installed on the purge cascade.

In order to calculate the mass of UF_6 released from the purge cascade, data sheets containing the records of daily purge rates for time periods of interest were entered into a database by the project team. The volume of gas purged each day and its UF_6 concentration were used to compute daily volumetric flow rates of UF_6 release. The daily flows of UF_6 were summed to estimate the total volume of UF_6 vented during each month. The mass of UF_6 released each month from the purge cascade was then derived from this volume.

The activity of UF_6 released each month in the purge cascade was computed by multiplying the grams of UF_6 by the specific activity of UF_6 at the assumed ^{235}U enrichment level (see Fig. F-3 in Appendix F). Table 2-3 summarizes the project team calculations of uranium releases through the purge cascade during the selected periods. Results of the project team's analysis demonstrated that historical releases from the purge cascade were less than 1 percent of total airborne uranium releases from K-25. Therefore, further project investigation for purposes of estimating releases for other periods was not warranted for the Task 6 screening assessment.

Table 2-3: Independently Calculated Purge Cascade Release Estimates

Period Reconstructed	Represents	^{235}U Enrichment	Uranium Released (kg)	Total Activity (Ci)
Dec. 1945 through Dec. 1946	Not Applicable	-35 %	0.076	0.00092
1953 through 1955	1947-1959	-93%	25	1.1
Mar. 1961 through Dec. 1961	1960-1963	-93%	2.3	0.1
1969	1964-1973	-3.5%	0.18	0.00022
1975	1974-1985	-3.5%	0.21	0.00025

The release estimates made for the purge cascade were included in the atmospheric release database along with all of the other data obtained from the detailed review of historical records. The following section describes how all of these data were combined by the project team to arrive at yearly release estimates for the K-25 site.

2.2.4 Airborne Release Estimates for the K-25 Complex

All of the data in the *Atmospheric Release, Cylinder Fire Tests*, Environment, *Environment* 2, *New Data 10-31-96, New Data 8-29-96* and *New Data 11-6-97* spreadsheets were summed for each calendar year and compared with the reported yearly release amounts from K/HS-95 (Lay and Rogers 1986) and K/HS-163 (Rogers 1985). For those years where the reported value was 10% or more greater than the project team's estimate, the difference was added to the estimated value. It was argued that for those years, DOE/AEC/K-25 reports had valid but unavailable data that had not yet been identified, and to account for these data, the differences were added in to the Task 6 estimates. This analysis is presented in the *10% Diff* worksheet (Table 2-4).

Table 2-4: Spreadsheet "10% Diff" Showing Comparisons Between Annual Sums from the Project Team's Assessment and Those from the Historical Release Histories Compiled by DOE

Date	Uranium (kg)	K/HS-95 (kg)	10% Difference	Add to ORHS (kg)	U (Ci)	U-235 (kg)	U-238 (kg)	Average Enrichment	Add Ci	Add U-235	Add U-238
1944	58										
1945	3043										
1946	1.4	1	0.0%								
1947	0.3	1	68.4%	0.7	0.01	0.15	0.17	87	0.04	0.60	0.09
1948	4.8	5	0.0%								
1949	78	45	0.0%								
1950	136	136	0.0%								
1951	200	146	0.0%								
1952	1211	345	0.0%								
1953	686	1307	47.5%	621	0.81	10	676	1.5	0.60	9.26	611.69
1954	81	68	0.0%								
1955	268	264	0.0%								
1956	263	225	0.0%								
1957	309	306	0.0%								
1958	1623	2711	40.2%	1088	1.09	11.48	1611	0.7	0.73	7.8	1081
1959	542	531	0.0%								
1960	1474	977	0.0%								
1961	783	773	0.0%								
1962	49	29	0.0%								
1963	1.0	1005	99.9%	1004	0.002	0.04	0.9	4.1	2.02	41.1	963
1964	4.8	7	31.9%	2.2	0.01	0.1	4.7	2.1	0.003	0.05	2.2
1965	29	269	89.2%	240	0.15	1230	27782	4.4	0.52	10.6	229.4
1966	0.6	1	44.0%	0.4	0.001	0.01	0.5	2.7	0.001	0.01	0.4
1967	0.0	2	100.0%	2.0	0	0	0	2.0	0.002	0.04	2.0
1968	1.8	1	0.0%								
1969	10	9	0.0%								
1970	6	8	25.3%	2.0	0.01	0.11	5.9	1.9	0.002	0.04	1.98
1971	51	21	0.0%								
1972	25	49	48.5%	24	0.02	0.38	24.8	1.5	0.02	0.4	23.4
1973	284	144	0.0%								
1974	70	622	88.7%	552	0.13	2.6	67.7	3.8	1.05	21.1	531
1975	93	371	74.9%	278	0.16	3.1	89.8	3.5	0.49	9.7	268
1976	114	45	0.0%								
1977	29	17	0.0%								
1978	13	19	33.8%	6.4	0.03	0.44	12.1	3.7	0.01	0.24	6.2
1979	46	25	0.0%								
1980	122	21	0.0%								
1981	69	5	0.0%								
1982	74	2	0.0%								
1983	0.7	2	66.8%	1.3	0.0011	0.02	0.6	3.4	0.002	0.04	1.3
1984	0.4	1	55.2%	0.6	0.0006	0.01	0.3	3.6	0.001	0.02	0.5
1985	1.0	1.222	17.1%	0.2	0.0005	0.01	0.3	3.8	0.0004	0.01	0.2
1986	0.2	0.2	0.0%								
1987	0.4										
1988	463										
1989	1.1										
1990	2.0										
1991	40										
1992	112										
1993	12										
1994	10										
1995	16										
Totals	12513	10517		3823	2	1259	30277		6	101	3722

Table 2-4 shows that the release totals compiled by the project team are greater than those reported in the K/HS-95 and K/HS-163 reports. This is before the differences between the DOE/AEC/K-25 totals and the project team's total are added to the Task 6 totals for years where the DOE/AEC/K-25 values exceed the Task 6 totals by 10% or more. This is indicative of the fact the project team's list is accounting for releases not considered in DOE/AEC/K-25 assessments. One example of these differences are the cylinder fire tests conducted in 1965. These losses did not occur in the course of normal plant operation and thus

were not considered in their assessment. Another example of unaccounted for mass is material lost from the purge cascade. The project team's release estimations include purge cascade releases determined for the ten calendar years 1945, 46, 53-55, 61, 68, 69, 75 and 76; but not for any other years. The S-50 Liquid Thermal Diffusion Plant is thought to represent a significant source of unaccounted for releases of natural and low-enriched uranium. However, only limited records associated with S-50 were available during this project, as K-25 was not given responsibility for these records once the plant was shut down in September of 1945. Task 5 (systematic document search task) investigators concluded that the records were likely archived by the War Department, and if any still exist, they may be located in the approximately 1,000 boxes of records maintained by the Defense Nuclear Agency at the National Archives and Records Administration in Washington, D.C.

The conclusion drawn by the project team is that even when the differences between the DOE/AEC/K-25 assessment and the project team's estimate are added in (see Table 2-5), the resulting total is an underestimate of actual releases. It should be noted that nearly one-third of all records reviewed during the Task 6 investigation describe releases without providing quantitative information regarding the amount of uranium released to the atmosphere.

The project team's annual estimates of the mass and activity of uranium released to the atmosphere from the K-25 complex are presented in Table 2-5. For purposes of the Task 6 screening assessment, the project team estimates that roughly 16,336 kilograms of uranium were released from the K-25/S-50 complex from 1944 to 1995.

Fig. 2-6 shows the release estimates in terms of total mass released from Table 2-5 plotted over time from 1944 to 1995. Fig. 2-7 shows the $^{234}U/^{235}U$ data in terms of activity, and Fig. 2-8 shows the ^{238}U activity. Table 2-6 provides a comparison of the team's release estimates and those reported by DOE/K-25. The two data sets are shown graphically in Fig. 2-9.

Table 2-5: Total Estimated Uranium Releases to Air from the K-25 Site

Year	Uranium (kg)	$^{234/235}$U (Ci)	^{238}U (Ci)
1944	58	0.019	0.019
1945	3000	1.0	1.0
1946	1.4	0.047	0.00022
1947	1.0	0.049	0.000086
1948	4.8	0.0022	0.0015
1949	78	0.019	0.026
1950	140	0.046	0.045
1951	200	0.063	0.067
1952	1200	0.38	0.40
1953	1300	0.98	0.43
1954	81	0.76	0.024
1955	270	0.17	0.089
1956	260	0.073	0.088
1957	300	0.11	0.10
1958	2700	0.92	0.90
1959	540	0.41	0.18
1960	1500	0.50	0.49
1961	780	0.34	0.26
1962	49	0.16	0.015
1963	1000	1.7	0.32
1964	7.0	0.0069	0.0023
1965	270	0.58	0.086
1966	1.0	0.0011	0.00033
1967	2.0	0.0017	0.00066
1968	1.8	0.00042	0.00060
1969	10	0.0038	0.0033
1970	8.0	0.0063	0.0026
1971	51	0.076	0.017
1972	49	0.032	0.016
1973	290	0.35	0.093
1974	620	0.98	0.20
1975	370	0.53	0.12
1976	110	0.21	0.037
1977	29	0.051	0.0093
1978	19	0.036	0.0062
1979	46	0.10	0.015
1980	120	0.16	0.040
1981	69	0.11	0.022
1982	74	0.086	0.024
1983	2.0	0.0028	0.00065
1984	1.0	0.0013	0.00029
1985	1.2	0.00077	0.00016
1986	0.20	0.00094	0.000058
1987	0.40	0.00016	0.00013
1988	460	0.16	0.15
1989	1.1	0.00037	0.00037
1990	2.0	0.00042	0.00067
1991	40	0.011	0.013
1992	110	0.026	0.038
1993	12	0.0041	0.0041
1994	10	0.0047	0.0033
1995	16	0.0012	0.0055
TOTAL	**16000**	**11**	**5.4**

NOTE: All values are rounded to two significant figure

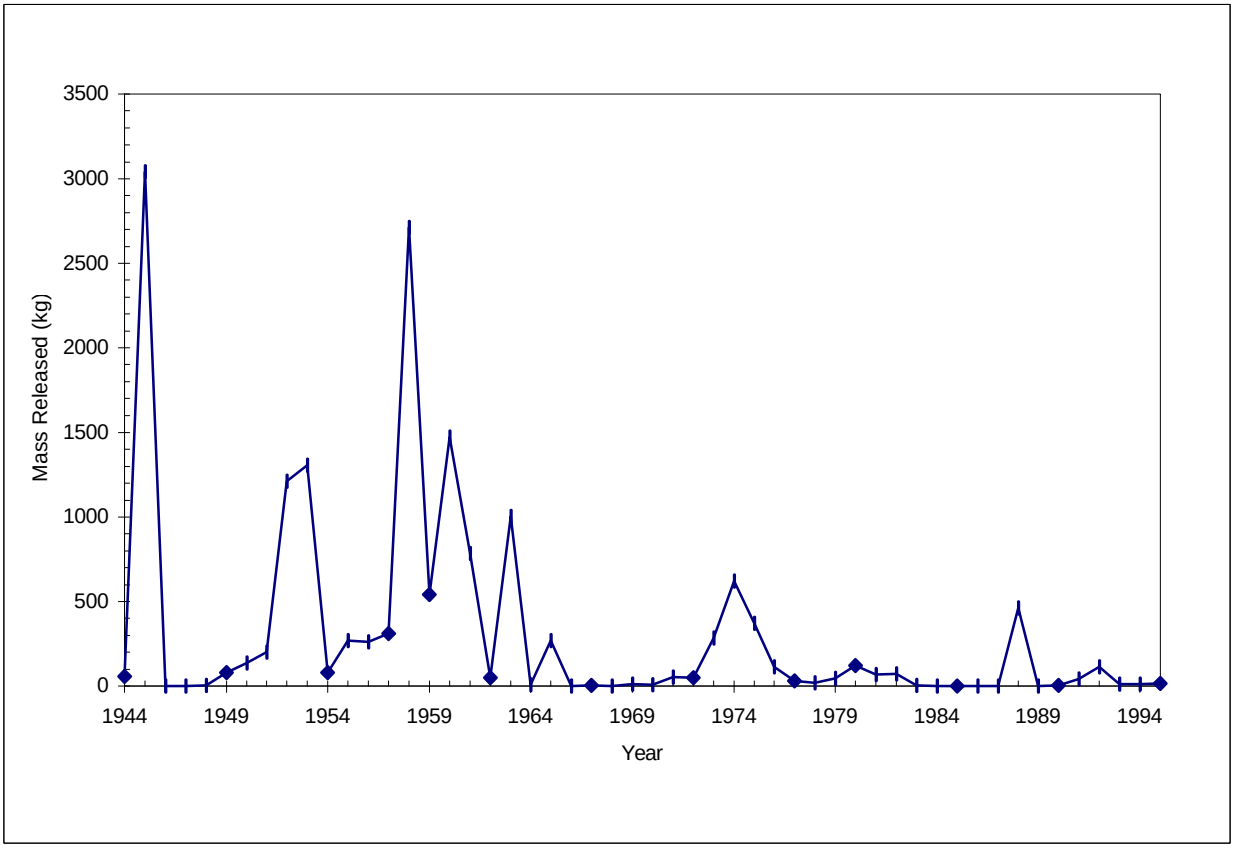


Figure 2-6: Estimates of Annual Airborne Uranium Releases from the K-25/S-50 Complex

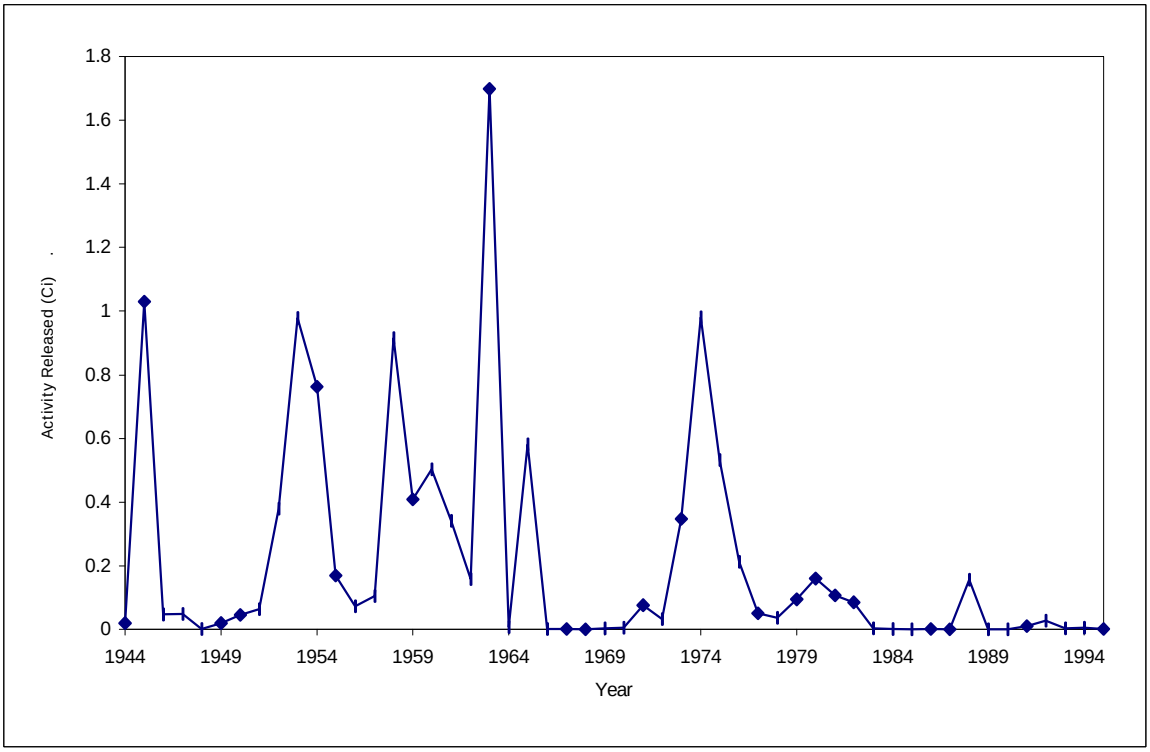


Figure 2-7: Task 6 Estimates of Annual Airborne $^{234/235}$U Releases from the K-25/S-50 Complex

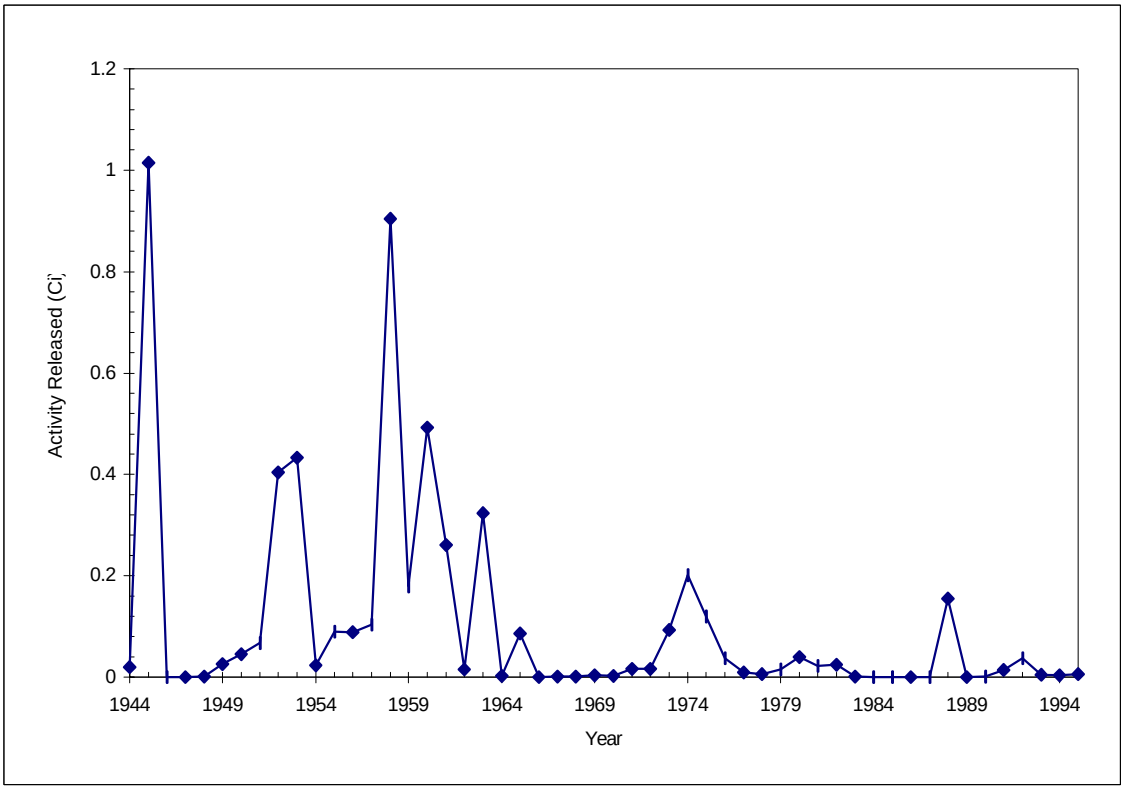


Figure 2-8: Task 6 Estimates of Annual Airborne ^{238}U Releases from the K-25/S-50 Complex

Table 2-6: K-25/S-50 Airborne Release Estimates[†]

Year	Task 6 Estimate (kg)	DOE Estimate (kg)
1944	58	0
1945	3000	0
1946	1.4	1
1947	1.0	1
1948	4.8	5
1949	80	45
1950	140	136
1951	200	146
1952	1200	345
1953	1300	1307
1954	80	68
1955	270	264
1956	260	225
1957	310	306
1958	2700	2711
1959	540	531
1960	1500	977
1961	780	773
1962	50	29
1963	1000	1005
1964	7.0	7
1965	270	269
1966	1.0	1
1967	2.0	2
1968	1.8	1
1969	10	9
1970	8.0	8
1971	50	21
1972	50	49
1973	290	144
1974	620	622
1975	370	371
1976	110	45
1977	29	17
1978	19	19
1979	46	25
1980	120	21
1981	69	5
1982	74	2
1983	2.0	2
1984	1.0	1
1985	1.2	1
1986	0.20	0
1987	0.40	0
1988	460	2
1989*		1
1990*		2
1991*		40
1992*		112
1993*		12
1994*		10
1995*		16
TOTAL	16,000	10,713

* Values for these years were based on releases reported by DOE. Release estimates for these late years were not independently reconstructed by the project team.

[†] DOE Estimates compiled from K/HS-95 and K/HS-163**.** Task 6 estimates are rounded to two significant figures.

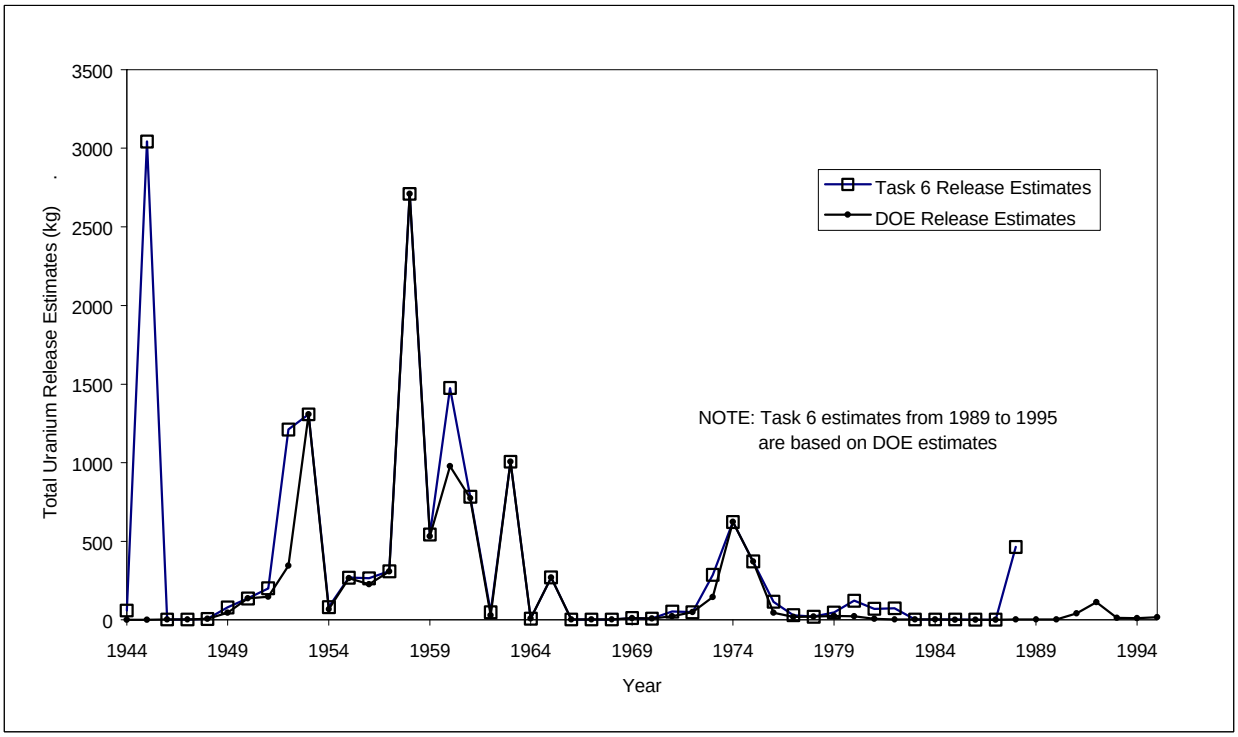


Figure 2-9: Task 6 and DOE Estimates of Annual Airborne Releases from the K-25/S-50 Complex

In addition to the fact that the total release estimation is known to understate the actual amount released, another factor to consider when reviewing the atmospheric release data is the importance of accurate knowledge of enrichment values. When assessing stochastic (cancer) risks associated with atmospheric releases of uranium, the quantity of interest is not as much the mass released as it is the corresponding activity. Because of the very different half-lives of the three uranium isotopes, the activity associated with a given release is a strong function of the enrichment. Thus, uncertainties in enrichment equate to uncertainties in activity and hence uncertainties in the screening assessment.

To establish if there were any years where there was the potential for bias in enrichment values, the mass data for each calendar year for total uranium were compared with the sums of the corresponding totals for ^{235}U and ^{238}U. Any differences between the total uranium values and the sums of the ^{235}U and ^{238}U values would be indicative of potential bias in enrichment, and thus the total activities asserted for those years. (Such differences would result from release data where only total mass was given and not masses for the individual isotopes.) The comparisons were carried out using only the actual release data from the database -- the differences between the database and DOE/AEC/K-25 values were not included in the Task 6 analysis. This comparison showed that of all the years considered, there were only two where there appeared to be the potential for enrichment bias in the documented releases. The two years were 1984 and 1985, which had total uranium release values of 0.4 kg and 1.0 kg, respectively. However, the enrichment values calculated for these two years agree well with those for this general era of K-25 operations, so it appears doubtful that the enrichment values are indeed inaccurate. Given that the rest of the comparisons

between total mass and the sums of the ^{235}U and ^{238}U data show good agreement, it would appear the enrichment values associated with these data do not suffer from any substantial bias. One should keep in mind this conclusion is made regarding the data currently in the release database and cannot be extended to any unquantified releases or to the data from K/HS-95 and K/HS-163 reports. There are many cases where known releases occurred, but quantitative information was not available to the project team. These events are not accounted for in the annual totals, nor can the enrichment values given in the database for any given year be reliably extended to apply to these events.

The comparison between the total uranium values and the sums of the ^{235}U and ^{238}U data for each year are shown in Table 2-7. The last two columns in this table are weighted averages of the enrichment data using three-year and five-year periods. This weighting was performed to see if the enrichment data appeared to be reasonably smooth over time or if they showed large variability. The NA entries in this table for 1967 is because release data were not available for that year. NA also appears in the three- and five-year weighted averages because the zero release for 1967 is being weighted into these computations. From the plots of these data shown in Fig. 2-10, it is evident that the enrichment data are quite variable over the years. This implies that the years for which the DOE/AEC/K-25 data represent the bulk of the total release, the enrichment (and thus activity) values for these years are subject to large uncertainties. The enrichments for these data were established based on what information was available in the release database. The variability in the enrichment data are indicative of the bias that could result, in that the release data used to establish the average enrichment for the DOE/AEC/K-25 data may not be representative of the bulk of the material released. The end result of the analysis is, that the years for which the differences between the DOE/AEC/K-25 data and the release database are used for the releases totals, potential uncertainties in enrichment. The magnitude of these uncertainties increases as the fraction of the total release that is derived from the DOE/AEC/K-25 assessment increases. Therefore, the years where the DOE/AEC/K-25 data make up the bulk of the release are those years with the highest uncertainty in enrichment and thus the highest uncertainty in activity. Note that these uncertainties are included in the release estimates presented in Table 2-5. Estimates of uncertainties associated with undocumented release events are not included in release estimates.

Table 2-7: Comparisons Between Total Uranium and the Sum of the ^{235}U and ^{238}U data

Year	U (kg)	U-235 (kg)	U-238 (kg)	Percent Difference	Percent Enrichment	Weighted Average 3-year	Weighted Average 5-year
1944	58.3	0.4	57.9	0.0%	0.71		
1945	3042.9	21.6	3021.1	0.0%	0.71	0.74	
1946	1.4	0.8	0.6	0.0%	55.40	0.74	0.74
1947	0.3	0.1	0.2	0.0%	46.53	15.17	0.74
1948	4.8	0.0	4.6	-3.3%	0.88	0.67	1.05
1949	77.7	0.4	77.3	0.0%	0.47	0.63	0.67
1950	135.6	1.0	134.3	-0.3%	0.71	0.63	0.64
1951	200.5	1.3	199.1	0.0%	0.65	0.65	0.89
1952	1210.9	7.8	1203.0	0.0%	0.64	0.91	1.36
1953	686.1	10.1	676.0	0.0%	1.47	1.47	1.37
1954	81.0	11.3	69.8	0.0%	13.88	2.36	1.34
1955	268.1	3.1	265.0	0.0%	1.14	2.58	1.74
1956	263.2	1.5	261.7	0.0%	0.55	0.79	1.16
1957	308.9	2.1	306.8	0.0%	0.69	0.69	0.86
1958	1622.5	11.5	1611.0	0.0%	0.71	0.86	0.79
1959	541.8	7.7	534.1	0.0%	1.41	0.82	0.81
1960	1473.9	10.6	1463.3	0.0%	0.72	0.88	0.88
1961	782.6	6.4	776.2	0.0%	0.81	0.87	0.97
1962	48.9	3.1	45.8	-0.1%	6.36	1.14	0.87
1963	1.0	0.0	0.9	-0.1%	3.93	5.94	1.25
1964	4.8	0.1	4.7	0.0%	2.07	3.93	5.33
1965	29.0	1.2	27.8	0.0%	4.24	3.91	NA
1966	0.6	0.0	0.5	0.0%	2.60	NA	NA
1967	0.0	0.0	0.0	NA	NA	NA	NA
1968	1.8	0.0	1.8	0.0%	0.43	NA	NA
1969	10.0	0.1	9.9	0.0%	0.83	1.13	NA
1970	6.0	0.1	5.9	0.0%	1.85	3.00	2.55
1971	51.3	1.8	49.3	-0.4%	3.56	2.81	2.86
1972	25.2	0.4	24.8	0.0%	1.50	2.93	3.04
1973	284.5	8.4	276.1	0.0%	2.94	2.98	3.11
1974	70.3	2.6	67.7	-0.1%	3.69	3.15	3.33
1975	93.0	3.1	89.8	0.0%	3.37	3.90	3.45
1976	114.4	5.1	111.5	1.9%	4.45	4.00	3.92
1977	28.8	1.2	27.5	0.0%	4.27	4.34	4.14
1978	12.6	0.4	12.1	-0.1%	3.53	4.55	3.96
1979	46.1	2.3	43.8	0.0%	5.00	3.60	3.71
1980	121.7	3.7	117.9	0.0%	3.08	3.65	3.45
1981	68.7	2.6	66.1	0.0%	3.76	3.18	3.45
1982	73.8	2.1	71.7	0.0%	2.80	3.27	3.18
1983	0.7	0.0	0.6	0.0%	3.25	2.80	3.25
1984	0.4	0.0	0.3	-19.8%	2.77	2.11	2.80
1985	1.0	0.0	0.3	-70.9%	1.07	2.73	2.59
1986	0.2	0.0	0.2	0.0%	11.24	2.27	0.72
1987	0.4	0.0	0.4	0.0%	0.91	0.72	0.72
1988	462.9	3.3	459.6	0.0%	0.71	0.71	0.71
1989	1.1	0.0	1.1	0.0%	0.71	0.71	0.69
1990	2.0	0.0	2.0	0.0%	0.39	0.51	0.65
1991	40.2	0.2	40.0	0.0%	0.52	0.46	0.48
1992	112.4	0.5	111.9	0.0%	0.44	0.48	0.51
1993	12.3	0.1	12.2	0.0%	0.66	0.51	0.47
1994	10.0	0.1	9.9	0.0%	1.04	0.49	
1995	16.2	0.0	16.2	0.0%	0.03		

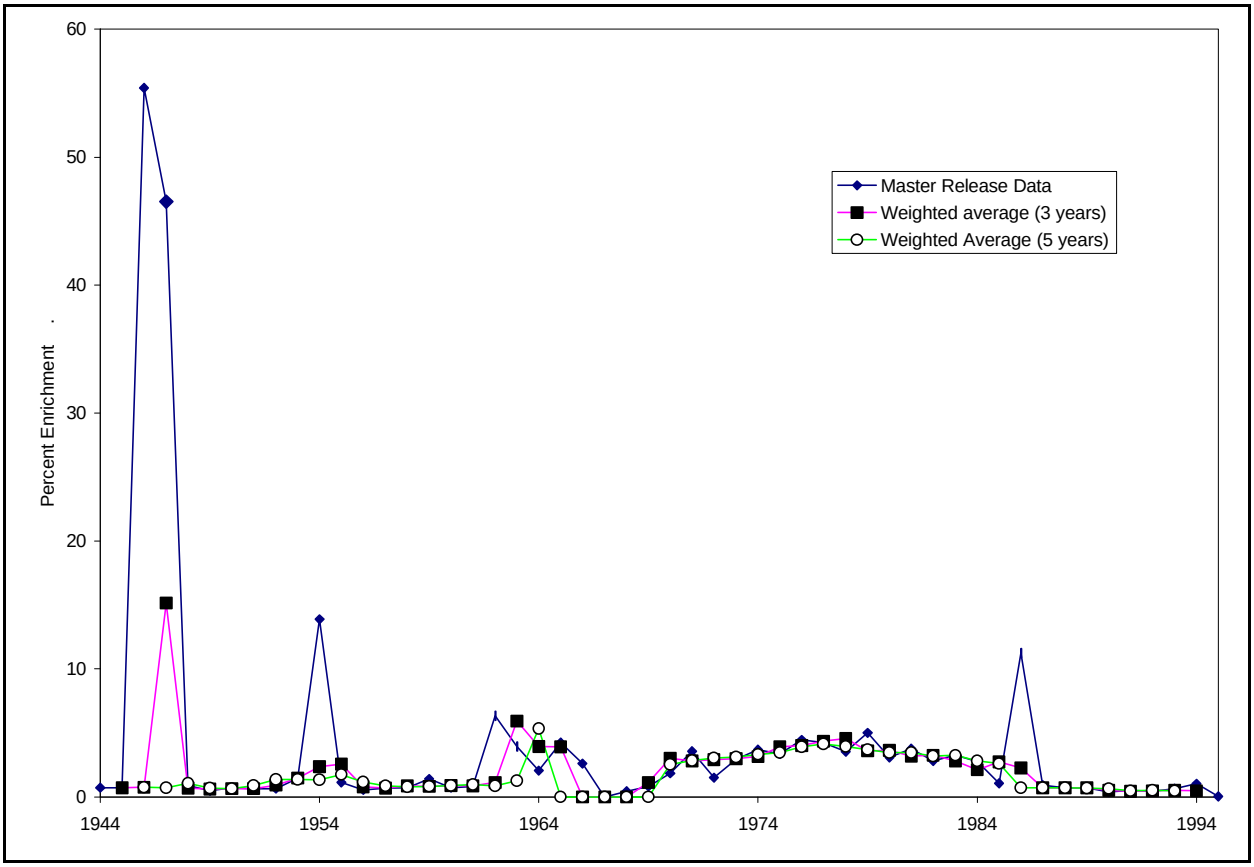


Figure 2-10: Plot of Actual and Weighted Average Enrichment Values

2.2.5 Future Refinements to the K-25/S-50 Release Estimations

This section describes possible refinements to K-25/S-50 release estimates that are warranted during the future study of ORR uranium. These observations were made by the project team as a result of the K-25/S-50 assessment documented in this report.

The Task 6 assessment of uranium at the K-25/S-50 plants concludes that estimates of uranium released have been understated by the AEC, DOE, and ORR site contractors. The Phase I Oak Ridge Dose Reconstruction Feasibility Study performed a screening evaluation for uranium using the DOE reported release estimates. Because of the concern that uranium, which was used in large quantities at the K-25 site, was not properly screened, the objectives of Task 6 were to evaluate the quality of effluent monitoring data and identify the potential for unmonitored or undocumented releases. DOE reported that the major unreported atmospheric releases of uranium were associated with the purge cascade. As a result, one of the initial study focuses of the Task 6 project team was the review of the purge cascade for a few operating periods that were selected to be indicative of operations during an era of similar operating conditions. This model showed that the purge cascade releases were small compared to the historically reported releases

and would not change the screening results from the feasibility study. During other portions of the Task 6 investigation, major discrepancies were found that were partially accounted for, resulting in Task 6 release estimates that likely underestimate actual releases. Many of these discrepancies were identified late in the project, and full study of their overall effect was not possible. During future study of uranium, it would be useful to refine the estimates in the following areas:

S-50 Facility- Estimated releases of uranium from the S-50 plant account for a large portion of the uncertainty in the total releases for K-25. The facility was operated for a year by a contractor who left after operations were completed, and compilations by DOE of K-25 site releases have never included the releases from S-50. Initial release estimates were made with the limited amount of data available. These indicated that S-50 releases in the single year of operation exceeded releases from the K-25 site. Currently, the location and availability of most of the S-50 records has been established, and additional investigation would permit retrieval and study to improve estimates of S-50 uranium releases.

Operations at K-1131 and K-1420- K-1131 was the first facility for on-site production of UF_6. As a pilot plant using a new process, operational problems resulted in releases that were quite large, especially during the first few years of operation. Together with the K-1420 decontamination facility, K-1131 is the source of about one half of the total material unaccounted for the K-25 site (amounting to tens of thousands of kilograms). Reports from the 1950s have asserted that releases during the first few years of operation amounted to thousands of kilograms, but the DOE asserted releases are less than one thousand kilograms. Recovery of the material release reports for K-1131 shows a number consistent with the DOE reported values. Additional study of this type has the potential to add additional quantities of uranium to the current Task 6 release estimates.

Cascade Releases- The Task 6 cascade release estimates are based release reports that describe release points such as leaks from Equipment to Indoor locations with entrainment into Ventilation systems and subsequent release to the Atmosphere (EIVA). Leaks from Cylinders (CIVA) were also found. These two pathways amounted to 43% of the total releases (reported in accountability release reports) at the K-25 site, but amounted to only 4% of the mass released. This is due, in part, to the lack of reported releases. The project team identified that many of these releases did occur, but could not find information that describes the quantities of uranium released. There was insufficient data to permit the data to be assembled into yearly release totals. The feasibility of using an alternate approach involving study of all years to determine if categories of releases could be fit into probability distributions and sampled (using Latin hypercube sampling methods) could be evaluated during future investigations of K-25 uranium. Results of a future study of this type have the potential to add additional quantities of uranium to the current Task 6 release estimates.

Stack Sampling- At present, the Task 6 estimates of uranium releases are not corrected for sample line loss. At the Y-12 plant, the project was able to find studies which demonstrated that failure to correct for sample line loss would under estimate uranium releases from stacks by a potential factor of four. A study of this type that describes potential biases in the K-25 release

estimates was not identified during the Task 6 investigation. A careful study of sample line loss for all reported stack releases would permit a proper assessment of the sample line loss factor. Results of a future study of this type have the potential to add additional quantities of uranium to the current Task 6 release estimates.

**Water Pathway-** Material release reports were collected that identify releases to storm sewer drains and settling ponds. These data were inconsistent with environmental monitoring records. As such, the environmental monitoring reports were used for screening without confirmation that the reports were consistent with operational releases. DOE documents concerning releases to local surface waters have noted that the sampling point was changed from the outfall of the settling pond to the pond's inlet. The change was reportedly made because the outfall measurements exceeded the amount of material being reported as lost via the accountability material release reports. Alternate explanations for the apparent discrepancy can be postulated, including resuspension of material previously deposited in the settling pond due to scouring and discard of uranium to the settling pond from undocumented sources such as waste waters from equipment decontamination activities. This task would provide greater assurance that other, unmonitored releases are included in the historical uranium releases estimates and serve to reconcile the differences between the plant losses and environmental measurements.

3.0 ESTIMATION OF URANIUM CONCENTRATIONS IN THE ENVIRONMENT

In order to estimate off-site screening indices from past Oak Ridge uranium releases, concentrations in air, surface water, and soil at locations of potential public exposure were estimated. Uranium concentrations in environmental media were estimated using fate and transport methods as well as established sources of environmental monitoring data. Reference locations were selected for atmospheric air dispersion modeling as well as identifying exposure point concentrations of uranium in soil and water. These reference locations represent established communities surrounding the ORR where residents resided during the years of uranium releases. Screening indices based on the uranium concentrations in the environment were then estimated for these reference locations. The approach and results of the screening assessment are presented in section 4 of this report.

To identify appropriate reference locations for the Task 6 screening assessment, the project team initially used an air dispersion modeling approach. Ground-level air concentrations were estimated for a 40 km by 47 km grid of locations that included several pre-selected receptor locations surrounding the site. Dispersion modeling quantitatively relates contaminant release rates to resulting average airborne concentrations at points of interest. For the Task 6 analysis, the initial off-site uranium concentrations were estimated using EPA's Industrial Source Complex Short Term (ISCST3) dispersion model, Version 96113 (USEPA 1995). For the initial ISCST3 analysis, a total of 1880 grid nodes were established covering an area of 40 km by 47 km. Each receptor grid represents an area of 1000 meter by 1000 meter; air concentrations were estimated at each grid node point. Using the results from the initial air dispersion modeling, the Task 6 team was able to identify off-site locations with the highest estimated air concentrations. Results of the initial atmospheric dispersion assessment were used to select specific communities where the maximally exposed individuals resided during years of past operations.

To derive final estimates of air concentrations for each screening assessment (*i.e.*, K-25, Y-12, and X-10), approaches specific to the characteristics of each reference location were employed. For the K-25/S-50 and X-10 screening assessments, the ISCST3 approach was considered to be adequate, since the terrains are relatively flat between the points of release and the reference locations. However, due to the unique characteristics of the topography surrounding the Y-12 facility and the nearest reference location (the Scarboro community), a classical air dispersion modeling approach would typically over-estimate the air concentrations. Therefore, estimates of air concentrations for the Y-12 reference location were derived using an empirical approach based on environmental measurement data and estimates of uranium releases.

The two main surface water bodies addressed in this analysis are the Clinch River and East Fork Poplar Creek. Estimates of uranium concentrations in these surface water bodies were derived from available environmental monitoring data and from reported surface water releases. Estimates of soil concentrations were based on available measurement data for samples collected near a specific reference location. Soil concentrations directly at specific reference locations were not available for the Task 6 assessment, as sampling locations used for soil measurements were based on the monitoring requirements for the facility or a particular study, and were not necessarily specific to a particular community.

3.1 Reference Locations

Due to the considerable distances between the Y-12, K-25/S-50 and X-10 facilities, three distinct reference locations were used for the three exposure assessments. While other potentially exposed communities were considered in the selection process, these reference locations represent residents who lived closest to the ORR facilities and would have received the highest exposures from past uranium releases and thus be associated with the highest screening indices derived by the project team. Factors such as patterns of habitation for the duration of the releases, as well as the existence of present day communities, were used to select the reference locations. The selected reference location for each ORR facility is shown in Figure 1-1.

3.1.1 Y-12 Reference Location - Scarboro Community

For the Y-12 screening assessment, the Scarboro community was selected as the reference location. The Scarboro community is located approximately 1 km north of Y-12 and is separated from the Y-12 facility by Pine Ridge. Even though the predominant wind direction at Y-12 is generally from the southwest or northeast (*i.e.*, up-valley or down-valley), the proximity of Scarboro to the Y-12 facility supports the selection of this area as the most suitable for screening both a maximally and "typically"exposed individual. The closest surface water body to the Scarboro community is East Fork Poplar Creek (EFPC), which runs along the south side of the Y-12 facility, turns toward the north and northwest, and passes about 0.4 mile to the northeast of the populated area of Scarboro at its closest point.

3.1.2 K-25/S-50 Reference Location - Union/Lawnville

For K-25/S-50 screening assessment, the Union/Lawnville community was selected as the reference location. This community is located approximately 4.5 km south-southwest of the K-25/S-50 facility. Based on the initial air dispersion modeling, as well as an assessment of areas around the K-25/S-50 facility that were inhabited during years of past operations, this community was selected as the most representative of maximum and typical exposures for the screening assessment. The location of the community is defined by the Union Church which is located on Lawnville Road, approximately 1 km north of Gallaher Road. The primary source for surface water is the Clinch River, which is approximately 1.5 km northeast of Union Church.

3.1.3 X-10 Reference Location - Jones Island (Clinch River)

The selected reference location for X-10 releases was in the area of Jones Island along the south bank of the Clinch River, approximately 5 km southwest of the site. This area represents the closest off-site location near X-10, and is along a predominant wind direction. The assessment included evaluation of air exposure pathways from X-10 releases, soil-related pathways based on maximum soil concentrations measured near the reference location, and surface water pathways reflecting fish consumption and recreational use of the Clinch River.

3.2 Evaluation of Air Concentrations

The ISCST3 air dispersion model is accepted by the United States Environmental Protection Agency as an appropriate air dispersion model for use in relatively flat terrain. The model uses the release rates from numerous types of release sources, including area, point, volume, and line sources, to predict ground-level concentrations at multiple reference locations. The ISCST3 modeling approach was used for the K-25/S-50 and X-10 facilities to estimate ground-level concentrations based on release source data, local meteorological data, and reference location data. The area surrounding the K-25/S-50 facility is relatively flat, and the reference location is within the same valley as K-25/S-50. The X-10 facility is located within Bethel Valley, where channeling effects are known to occur. Based on ISCST3 modeling of airborne ^{131}I releases from X-10 and analysis of ambient monitoring data, flat terrain modeling is considered appropriate for a screening assessment of X-10 uranium releases.

Due the unique characteristics of the topography surrounding the Y-12 facility, a classical air dispersion modeling technique, such as ISCST3, would overestimate air concentrations at the Scarboro reference location. The presence of Pine Ridge to the north of the Y-12 facility means that the flat terrain approach used by ISCST3 would not account for the attenuation and redirection of wind flow away from the Scarboro community, which is located 1 km north of the Y-12 fence-line. Pine Ridge represents an elevation change of approximately 200-400 feet from Bear Creek valley. The change in elevation varies across the length of the Y-12 facility. Given the relative height of Pine Ridge, the majority of Y-12 release points are at a lower altitude than the intervening ridge. The ISCST3 model does not account for the presence of terrain above the height of release, and thus is not appropriate for use at Y-12. Algorithms for complex terrain are available for the ISCST3 model, however, it is questionable if these algorithms could account for the abrupt change in topography. Any attempts to use complex terrain modeling would require additional study that was beyond the scope of the Task 6 assessment. In addition, the relative altitude of the Scarboro community is below the top of Pine Ridge, which further complicates the dispersion characteristics. Modeling these characteristics would require a substantial effort and was beyond the scope of this screening assessment.

An empirical approach using measured ambient air concentrations was developed. An empirical P/Q approach was used to describe the relationship between measured air concentrations at the Scarboro monitoring station and Y-12 uranium release estimates generated by the project team or Y-12 contractors. This relationship was then used to estimate air concentrations at Scarboro for all years for which release estimates were determined.

Based on the annual releases from each individual site (Y-12, K-25/S-50, and X-10), predictions of air concentrations at each exposure grid location were made using the methodologies discussed above. With releases from multiple facilities, there is the potential for combined impacts at each exposure point. To evaluate such effects, an additional assessment of the combined effect from multiple sites to a reference location was conducted by the project team. To complete the assessment, the project team examined releases from K-25/S-50 that are transported to the Scarboro community using the ISCST3 model and concluded that contributions from K-25 and S-50 are minor in comparison to the Y-12 releases

transported to Scarboro. The contribution of K-25/S-50 releases to the Scarboro screening index is described in Section 4.

3.2.1 Air Dispersion Modeling for K-25/S-50 and X-10 Releases

The ISCST3 model was used to calculate airborne uranium concentrations from the K-25/S-50 and X-10 plant releases. The facility-specific information used to provide an accurate representation of effects of releases from each release point included local meteorological data, an appropriate receptor grid, and parameters that specify options that are to be active in execution of the modeling program. The parameters chosen are described below.

3.2.1.1 Meteorological Data

Meteorological data obtained from the "MTE Station" on the Y-12 site for the year 1987 were used for the dispersion modeling in this screening-level assessment. These data were in the form of hourly-average values of wind speed, wind direction, temperature, stability class, and mixing height. The Y-12 meteorological data were selected to represent wind patterns at each site after comparison of wind frequency distributions (wind roses) for the Y-12, K-25/S-50, and X-10 plants. The ridge and valley influence of the local terrain results in similar wind distributions at all three sites. When the exposure analysis for uranium releases is carried beyond this screening phase, dispersion modeling using the meteorological data measured at each individual site would be an appropriate refinement for a formal dose reconstruction.

3.2.1.2 Specification of Model Options

The following options were used in the ISCST3 modeling analysis:

(1) Mixing heights (the heights above the surface within which effluents normally become mixed) and dispersion curves (numerical expressions that represent the predicted rate of dispersion of airborne contaminants as a function of distance downwind and crosswind) were set to be representative of conditions in rural areas.

(2) Coefficients and equations that predict how wind speeds and air temperatures vary with height above the ground were set to their default values for rural settings.

(3) The height of calculation for each reference location was set at 1.5 meters (about 5 feet) above the local ground surface.

(4) Airborne effluents, such as those from exhaust stacks, can experience plume rise due to the momentum of the exhaust stream and differences in temperature compared to ambient air. Calculations at all reference locations were set to reflect the final results of plume rise calculations.

(5) The program was directed to include the effects of calm winds on effluent transport and dispersion. This can be important near Oak Ridge, where frequencies of calm conditions are quite high compared to many regions of the U.S.

3.2.1.3 Source-Specific Release Parameters for Modeling

Releases from each facility of interest were modeled as point sources, as releases occurred from discrete exhaust stacks or building vents. For the X-10 site, a single release point was specified, the Chemical Processing Pilot Plant stack. For the K-25/S-50 site, a single hypothetical release point was specified in the middle of the U-shaped K-25 Building. Source-specific parameters necessary to characterize a release source for air dispersion modeling include stack height and diameter, exit velocity or volumetric flow rate, and exit temperature. The values used for the K-25/S-50 and X-10 stacks are given in Table 3-1.

Table 3-1: Stack Parameters used for Air Dispersion Modeling of X-10 and K-25/S-50 Releases

Parameter	X-10 Stack	K-25 Stack
Stack Height (m)	60.96	22.56
Exit Temperature (K)	363	293.15
Stack Diameter (m)	1.52	1.94
Exit Velocity (m s^{-1})	31	9.8

3.2.1.4 Dispersion Modeling Results

The ISCST3 modeling that was used to estimate annual-average off-site uranium concentrations in air was based on unit release rates (i.e., 1 g s^{-1} or 1 Ci s^{-1}) from each of the sources described earlier. The resulting relative concentration (analytical P/Q) at each grid point from each source had the units of s m^{-3}; subsequent multiplication by the annual release rate (in g s^{-1} or Ci s^{-1}) yielded an estimated annual average concentration at that point in g m^{-3} or Ci m^{-3}. The grid locations used to represent the reference locations, and the P/Q values generated by the ISCST3 code are presented in Table 3-2.

Table 3-2: Air Dispersion Results for X-10 and K-25/S-50 Releases

Release Facility	Reference Location	UTM Coordinates of Reference Location (m)		Analytical P/Q (s m^{-3})
		UTM-X	UTM-Y	
K-25/S-50	Union/Lawnville	733,000	3,976,000	7.4×10^{-7}
X-10	Jones Island	737,000	3,976,000	3.4×10^{-8}

3.2.1.5 Predicted Air Concentrations from Past K-25/S-50 Releases

Using the analytical P/Q for the Union/Lawnville area presented in Table 3-2, along with the annual K-25 uranium releases, the air concentrations of the two uranium isotopes can be estimated. The annual average air concentrations at Union are presented in Table 3-3 along with the range of values and the years corresponding to their release. All annual air concentrations are presented in Figure 3-1; tabulated values are presented in Table 3-4.

Table 3-3: Calculated Annual Average Air Concentrations (fCi m^{-3}) at Union/Lawnville from K-25 Releases

	$^{234/235}U$	^{238}U
Annual Average Air Concentration	5.1	2.4
Maximum Concentration (Release Year)	40 (1963)	24 (1945)
Minimum Concentration (Release Year)	0.0038 (1987)	0.0014 (1986)

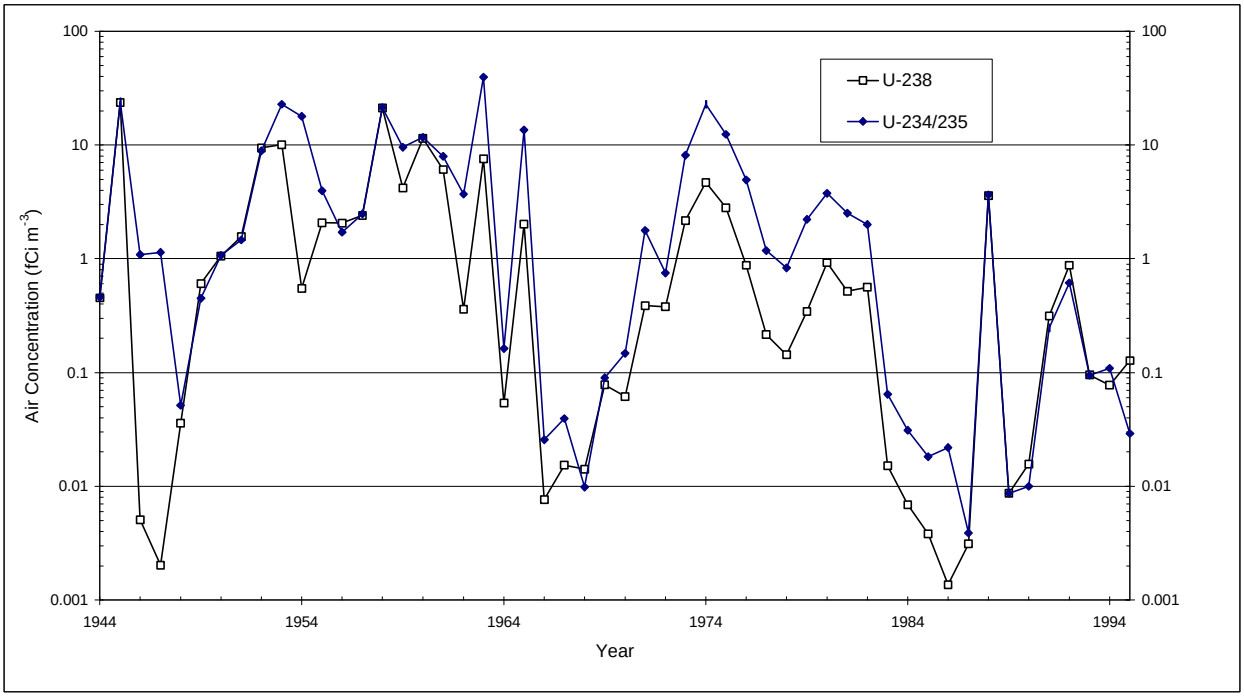


Figure 3-1: Calculated Annual Average Air Concentrations (fCi m^{-3}) at Union/Lawnville from K-25 Releases

Table 3-4: Calculated Annual Air Concentrations (fCi m^{-3}) at Union/Lawnville from K-25 Releases

Year	$^{234/235}U$	^{238}U
1944	0.46	0.45
1945	24	24
1946	1.1	0.0051
1947	1.1	0.0020
1948	0.052	0.036
1949	0.45	0.61
1950	1.1	1.1
1951	1.5	1.6
1952	8.9	9.4
1953	23	10
1954	18	0.55
1955	4.0	2.1
1956	1.7	2.1
1957	2.5	2.4
1958	21	21
1959	9.5	4.2
1960	12	12
1961	8.0	6.1
1962	3.7	0.36
1963	40	7.6
1964	0.16	0.054
1965	14	2.0
1966	0.026	0.0076
1967	0.039	0.015
1968	0.0098	0.014
1969	0.089	0.078
1970	0.15	0.062
1971	1.8	0.39
1972	0.75	0.38
1973	8.1	2.2
1974	23	4.7
1975	12	2.8
1976	5.0	0.88
1977	1.2	0.22
1978	0.83	0.14
1979	2.2	0.34
1980	3.7	0.93
1981	2.5	0.52
1982	2.0	0.56
1983	0.064	0.015
1984	0.031	0.0069
1985	0.018	0.0038
1986	0.022	0.0014
1987	0.0038	0.0031
1988	3.7	3.6
1989	0.0086	0.0086
1990	0.099	0.016
1991	0.25	0.31
1992	0.61	0.87
1993	0.095	0.096
1994	0.11	0.078
1995	0.029	0.13

NOTE: All values are rounded to two significant figures

3.2.1.6 Predicted Air Concentrations from Past X-10 Releases

As the uranium releases from X-10 included in this analysis occurred during the first 14 years of operation (1944-1957), there are no contributions to the total screening index from X-10 air releases beyond 1957. Using the analytical P/Q for Jones Island presented in Table 3-2, along with the annual X-10 uranium releases, the air concentrations of the two uranium isotopes can be estimated. The annual average air concentrations at Jones Island are presented in Table 3-5 along with the range of values and the years corresponding to their release. All annual air concentrations are presented in Figure 3-2; tabulated values are presented in Table 3-6.

Table 3-5: Calculated Annual Average Air Concentrations (fCi m^{-3}) at Jones Island from X-10 Releases

	$^{234/235}U$	^{238}U
Annual Average Air Concentration	0.0029	0.078
Maximum Concentration (Release Year)	0.039 (1946)	0.84 (1946)
Minimum Concentration (Release Year)	0.000038 (1949-1957)	0.00084 (1949-1957)

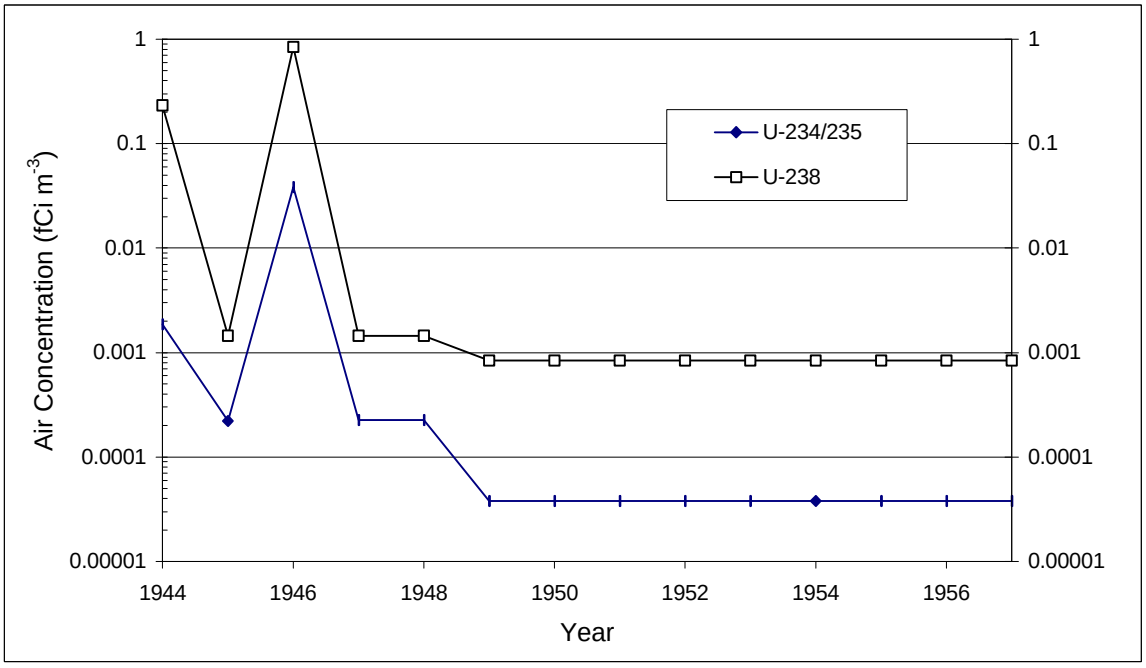


Figure 3-2: Calculated Annual Average Air Concentrations (fCi m^{-3}) at Jones Island from X-10 Releases

Table 3-6: Calculated Annual Air Concentrations (fCi m^{-3}) at Jones Island from X-10 Releases

Year	$^{234/235}U$	^{238}U
1944	0.0018	0.23
1945	0.00022	0.0014
1946	0.038	0.84
1947	0.00023	0.0014
1948	0.00023	0.0014
1949	0.000038	0.00084
1950	0.000038	0.00084
1951	0.000038	0.00084
1952	0.000038	0.00084
1953	0.000038	0.00084
1954	0.000038	0.00084
1955	0.000038	0.00084
1956	0.000038	0.00084
1957	0.000038	0.00084

NOTE: All values rounded to two significant figures

3.2.2 Air Dispersion Modeling for Y-12 Releases

As discussed earlier, the complexities of the terrain surrounding the Y-12 facility prohibit the use of the ISCST3 model to predict air concentrations at the Scarboro Community. Instead of an analytical approach to estimating air concentrations at Scarboro, an empirical approach based on measured air concentrations was used. This empirical P/Q (s m^{-3}) value was based on measured air concentrations in the Scarboro community and the Y-12 uranium release estimates generated by the Task 6 team. Air monitoring data were available for the Scarboro community, however, they were limited to the period 1986 to 1995. To estimate air concentrations prior to 1986, a relationship between air concentrations at Scarboro, P (pCi m^{-3}), and the Y-12 release rate estimates, Q (pCi s^{-1}), was derived. Using this relationship, air concentrations for all years (1944-1995) were estimated. Even though air concentrations at Scarboro were available for the period 1986 through 1995, the evaluated air concentrations using the empirical P/Q approach for these years was used.

3.2.2.1 Sources of Uranium Air Monitoring Data for Scarboro

A continuous air monitoring station was installed in the Scarboro community during the 3rd quarter of 1986, and was operational and generating data by the 4th quarter. This air monitoring station, called Station #46, was placed in the Scarboro community just west of the Mount Zion Church on Tuskegee Drive, approximately 140 meters west of the Scarboro Community Center. Figure I-1 in Appendix I contains a map showing the location of the Scarboro station. Since installation, the monitoring station has provided quarterly and annual measurements of ^{234}U, ^{235}U and ^{238}U in air and has been operated and maintained by ORNL. This station represents the closest measurement location to the north side of Pine Ridge (Figure 3-3). The station is operated as part of the DOE ORR air monitoring network, and was initially designated as A46. Later reports referred to this sampling location as Station 46. For the period since Station 46

began operation in 1986, 10 years of annual average uranium isotopic measurement data are available for the empirical P/Q evaluation.

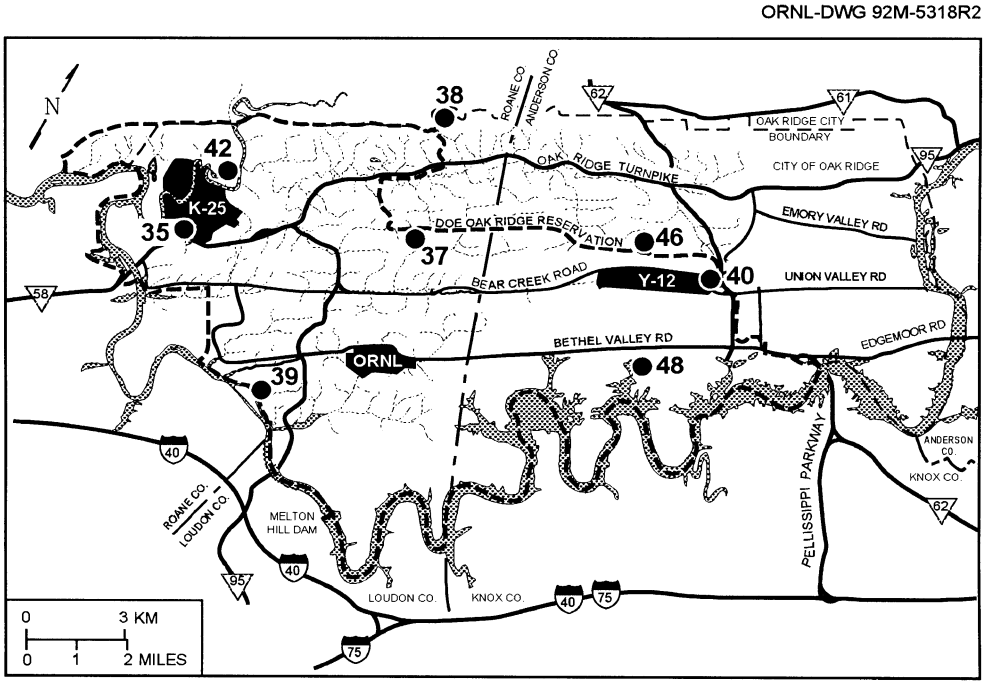


Figure 3-3: Locations of Air Monitoring Stations Including Station 46

The primary sources of information for reported uranium concentrations at the Scarboro station are the environmental reports that are issued annually by the Department of Energy and their prime contractors (*e.g.*, Martin Marietta Energy Systems, Inc.). These reports have been issued since 1971, and are generally given titles such as *Oak Ridge Reservation Environmental Report for 1987*. These reports provide documentation as to the regulatory status of the facilities for a particular reporting period, general site characteristics, effluent monitoring data, and a compilation of results of environmental monitoring programs. Detailed radionuclide concentrations are usually presented in Volume 2 of these reports. The sources of information and a document reference list are presented in Table 3-7.

Table 3-7: Information Sources for Uranium Air Monitoring Data

Year	Document	DOE Ref.
1986	Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservation and Surrounding Environs During 1986. Volume 2: Data Presentation.	ES/ESH-1/V2
1987	Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservation and Surrounding Environs During 1987. Volume 2: Data Presentation.	ES/ESH-4/V2
1988	Oak Ridge Reservation Environmental Report for 1988. Volume 2: Data Presentation.	ES/ESH-8/V2
1989	Oak Ridge Reservation Environmental Report for 1989. Volume 2: Data Presentation.	ES/ESH-13/V2
1990	Oak Ridge Reservation Environmental Report for 1990. Volume 2: Data Presentation.	Errata for 1990 in ES/ESH-22/V2
1991	Oak Ridge Reservation Environmental Report for 1991. Volume 2: Data Presentation.	ES/ESH-22/V2
1992	Oak Ridge Reservation Environmental Report for 1992. Volume 2: Data Presentation.	ES/ESH-31/V2
1993	Environmental Monitoring and Surveillance on the Oak Ridge Reservation: 1993 Data.	ES/ESH-69
1994	Environmental Monitoring and Surveillance on the Oak Ridge Reservation: 1994 Data.	ES/ESH-69
1995	Environmental Monitoring and Surveillance on the Oak Ridge Reservation: 1995 Data.	ES/ESH-69

3.2.2.2 Quality of Scarboro Uranium Air Monitoring Data

As early as 1960, ambient air monitors were placed throughout the DOE Oak Ridge Reservation and surrounding communities for purposes of detecting the presence of contaminants released from the ORR and estimating concentrations of contaminants in air. The choice of location for the Scarboro monitor was reportedly based on discussions with community members and siting criteria that would minimize biases in the collection of representative samples. This station has included at different times a particulate air sampler, a noble gas collection and analysis system, a silica gel tritium trap and monitor, a pressurized ion chamber for measuring gross gamma exposure rates, a wet and dry deposition collection tray, and a rain gauge. All sampling equipment is housed in or near a small building on a 15' x 25' concrete slab enclosed on all sides by a chain-link security fence. Figure I-2 in Appendix I provides a plan view of the monitoring station. Since its inception in 1986, particulate air samples from the station have been used by ORNL to estimate uranium air concentrations within the Scarboro community.

The Task 6 project team conducted reviews of the quality of the air sampling practices and methods used to evaluate measurement data and report uranium concentrations in air. The purpose of these reviews was to determine if the methods used by ORNL for estimating uranium air concentrations measured at Scarboro meet minimum acceptable industry standards and yielded results of sufficient quality to be used in the Task 6 P/Q evaluation presented in Section 3.2.2.

The project team's review of the Scarboro monitor and sampling results involved review of relevant documents and interviews with active and retired ORNL workers. In addition, the project team submitted a list of questions to ORNL staff regarding historical air sampling practices and techniques used to estimate Scarboro uranium air concentrations. Five steps used by the project team in evaluating the quality of Scarboro air montioring data were:

1) review of documents that describe methods and procedures for air sample collection and measurement of radioactivity collected on filter samples,

2) a project team visit to the ORNL Analytical Services Laboratory to observed laboratory procedures and handling of air samples by lab personnel,

3) interviews with ORNL Analytical and Health Physics field personnel,

4) interviews with ORNL Environmental Monitoring staff regarding data collection and reporting of uranium air concentrations based on results of Scarboro samples, and

5) site visit by project team members to the Scarboro station.

Specific topics of interest to this review and conclusions drawn from The Task 6 investigation include:

The 1990 Tiger Team assessment, findings regarding the Scarboro ambient air monitoring station and corrective actions implemented by ORNL in response to the 1990 Tiger Team finding–

> The 1990 Tiger Team audit found that the Scarboro monitor may not have been providing representative measurements to assess radiation dose to members of the public, in accordance with federal regulatory criteria. The audit found that potential influences on measurements may have occurred as a result of an air conditioning unit located beneath the particulate air sampler and wooden slats mounted to the chain-link security fence that surrounds the monitoring station.
>
> In response to the Tiger Team finding, ORNL relocated the air conditioning unit and removed wooden slats from the security fence that may have had an influence on the collection of airborne particles. Conclusions drawn from the project team review of monitoring data do not indicate that an observable increase in measured uranium concentrations occurred after the changes were made to the monitoring station, taking into account changes in Y-12 uranium releases. Any improvements in the collection of

representative air samples at Scarboro appear to be minimal and would have limited, if any, impact on the Task 6 P/Q approach for estimating annual uranium air concentrations in the Scarboro community used in the Task 6 screening assessment.

Sample collection frequencies, sample collection methods used for air particulate samples, and types of samples (*i.e.*, individual or composite samples)–

Since 1986, weekly air samples were collected and analyzed for total alpha radioactivity. Weekly samples collected during a given quarter were then composited and submitted to the ORNL laboratory services for uranium isotopic analyses. These sampling frequencies are considered adequate for measuring airborne uranium, assessing trends in concentrations over an extended period of time, and identifying unusual results or episodic release events. A complete set of isotopic measurement results for the period 1986 through 1995 were reviewed by the project team and determined to be adequate for the P/Q evaluation.

Operational characteristics of the particulate air sampler (*e.g.*, volume of air, types of filter paper, design of air sampler/filter housing/particulate inlets)–

Since initial operations, standard particulate air sampling equipment has been used at the Scarboro station and is considered to be adequate for collecting representative air samples for the purpose of determining uranium concentrations. The initial particulate air sampler was a low-volume system consisting of a 47 millimeter diameter Whatman 41 glass fiber filter with a reported particle collection efficiency of 99.99 percent. This type of filter is commonly used in the nuclear industry for evaluation of airborne radioactivity. The filter and filter holder were mounted to the south side of the instrument building as shown in Figure I-2 of Appendix I. Airborne particles were collected on the filter by continuously drawing air through the filter at a rate of two cubic feet per minute. In 1993, ORNL installed a high-volume particulate sampler that draws air through a 8" x 10" glass fiber filter at a rate of 35 cubic feet per minute. The new sampler replaced the original 47 millimeter sampler due to lower levels of uranium present in the air. Figure I-2 in Appendix I shows the locations of the two samplers. Both samplers used standard pumps to draw air through the particulate filters and employed an electronic volume totalizer that recorded the volume of air drawn through the filter for a specified period of time. The volume totalizer also recorded interruptions of airflow.

Verification methods/calibration procedures used to assert volume of air collected–

The project team reviewed procedures and interviewed ORNL workers to ascertain how ORNL routinely checked to ensure the accuracy of air sample collection. Weekly instrument calibration of the volume totalizer and vacuum system were performed, and have shown that measured air flow rates are within plus or minus 2 percent of the actual flow rates.

Handling procedures for air samples–

Weekly samples collected from the air samplers were placed in plastic bags and transported to ORNL's Analytical Laboratory for gross alpha measurement and specific isotopic analyses. The volume of air collected for each sample was recorded and submitted to the lab along with the sample. Handling of air samples were performed in such a manner to ensure minimal loss of activity collected on the surfaces of the air filters and are consistent with industry standards. The project team did not identify any areas in the ORNL sample handling procedures that would compromise the integrity of the samples or bias estimates of uranium concentrations.

Types of radiation detection systems used to screen air filters for radioactivity and ascertain uranium concentrations based on single or composite samples–

Gas proportional counters were used to measure weekly air samples for alpha radioactivity content. Weekly samples received at the lab were loaded into metal sample holders, counted for five minutes, and stored for quarterly composites. Composite samples were then measured once a quarter for uranium isotopic concentrations using an ion exchange sample separation and alpha spectroscopy. A uranium-232 tracer was added to the dissolved sample for determing the amount of uranium recovered from the sample that is measured for alpha spectroscopy. Unique, characteristic alpha energies associated with ^{232}U, ^{235}U, and ^{238}U allow laboratory technicians to quantify the specific amount of activity of each uranium isotope present in each sample. A sample alpha spectroscopy report and alpha spectrum for a Scarboro sample are shown in Figures I-3 and I-4, respectively, of Appendix I. Figure I-5 shows a calibration spectrum of known uranium activity that is used to estimate the amount of uranium collected on Scarboro samples. Typical detection limits for alpha spectrographic analysis are presented in Table 3-8. Sample preparation and calibration procedures for the equipment used were found to be consistent with industry standards. All radiation measurement equipment is periodically calibrated with traceable radionuclide standards.

Table 3-8: Typical Limits of Detection for all Uranium Isotopes

Uranium Isotope	Limit of Detection (fCi m^{-3})
^{234}U	0.03
^{235}U	0.0043
^{238}U	0.0022

Sampling procedures reviewed by the project team included:

- Calibration Procedure for Sierra Side Track Flow Controller/Totalizer
- Calibration Procedure for HI-Q High Volume Particulate Samplers
- Ambient Air Sampling for Particulates and Adsorbable Gases
- Collection of Samples from Ambient Air Samplers for Uranium
- Preparation of Nonaqueous Samples for Radiochemical Analyses
- Radiochemical Method for Uranium in Air Filters

In summary, procedures and methods that have been used to collect and analyze air samples for uranium concentrations at the Scarboro location were deemed by the project team to be of adequate quality for use in the Scarboro P/Q evaluation presented below. The methods employed by ORNL are consistent with industry standards and are capable of producing reliable estimates of uranium concentrations in Scarboro.

3.2.2.3 Uranium Air Concentrations at Scarboro

The reported air concentrations at Scarboro, published in the documents referenced in Table 3-7, are presented in Table 3-9. Figure 3-4 shows the variation of total uranium air concentrations measured at Scarboro for the period 1986 through 1995. Reported values have been converted to fCi m^{-3}, and the ^{234}U and ^{235}U concentrations have been summed in column 4 so as to be consistent with the Y-12 releases reported in earlier sections of this document.

By comparing the total uranium activity measured at Scarboro with the background concentrations measured at the Remote Air Monitoring stations (RAM), it is evident that releases from Y-12 are transported across Pine Ridge to the Scarboro community. The RAM stations are located at various locations outside the Oak Ridge Reservation, at distances of 19 to 21 km. The RAM stations that were operational during the period 1986-1995 include Norris Dam, Fort Louden Dam, Douglas Dam, Great Falls Dam, Dale Hollow Dam, and Knoxville. Not all these stations reported uranium air concentrations during the entire period, hence the RAM data used in this analysis was an annual average of all operational stations. For comparison, measurements reported from Station 41 (Oak Ridge Turnpike and Illinois Ave.) and Station 40 (East end of Y-12) are presented with the RAM and Station 46 (Scarboro) data in Figure 3-5.

Table 3-9: Reported Uranium Air Concentrations (fCi m^{-3}) Measured at the Scarboro Community Monitoring Station

Year	^{234}U	^{235}U	$^{234}U + ^{235}U$	^{238}U	Total Uranium Activity
1986	0.57	0.045	0.615	0.078	0.693
1987	0.97	0.14	1.11	0.16	1.27
1988	0.53	0.071	0.601	0.11	0.711
1989	0.36	0.015	0.375	0.052	0.427
1990	0.21	0.027	0.237	0.031	0.268
1991	0.16	0.01	0.17	0.029	0.199
1992	0.21	0.052	0.262	0.032	0.294
1993	0.1	0.012	0.112	0.018	0.13
1994	0.044	0.006	0.05	0.015	0.065
1995	0.026	0.0017	0.0277	0.011	0.0387

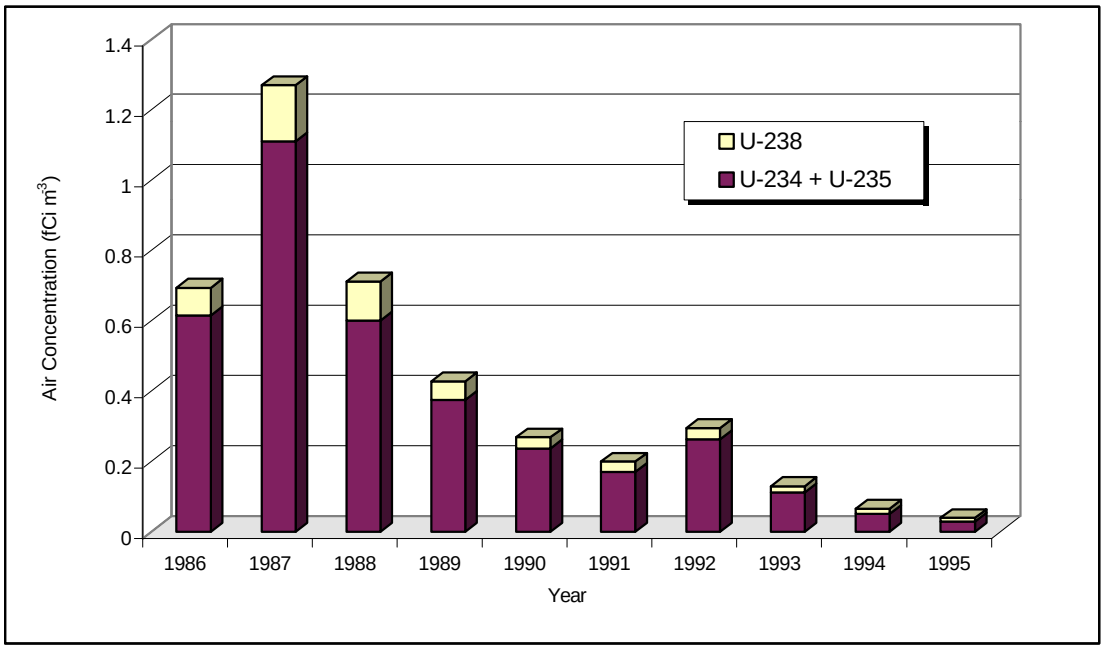


Figure 3-4: Uranium Air Concentrations (fCi m^{-3}) Measured at the Scarboro Community Monitoring Station

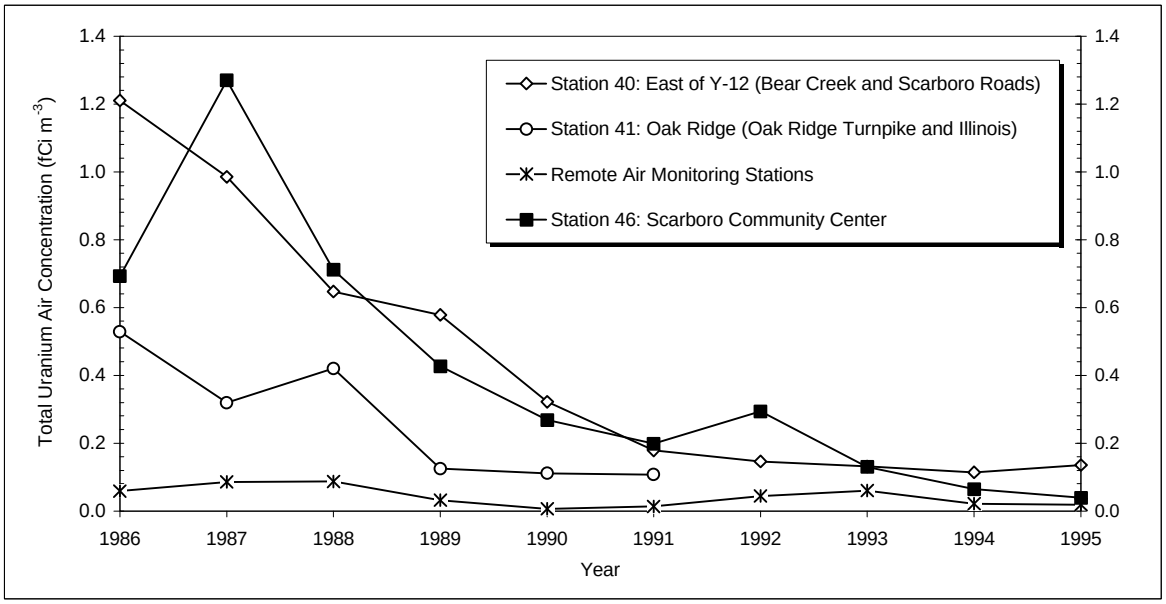


Figure 3-5: Total Uranium Air Concentrations (fCi m^{-3}) from Monitoring Stations in the Vicinity of the Y-12 Facility and from the Remote Air Monitoring (RAM) Stations

3.2.2.4 Evaluation of an Empirical χ/Q for Y-12

By using the air concentrations measured at the Scarboro community monitoring station and the Y-12 uranium releases estimated by the Task 6 team, an empirical relationship was developed that was used to predict air concentrations at Scarboro. The empirical χ/Q is the ratio of measured air concentration to release rate and is expressed in terms of s m^{-3}.

$$Empirical\ \chi/Q\ (s\ m^{\&3})\ '\ \frac{Uranium\ Air\ Concentration\ (pCi\ m^{\&3})}{Uranium\ Release\ Rate\ (pCi\ s^{\&1})}$$

The uranium release rates were based on the Y-12 release estimates calculated by the Task 6 team (or reported by DOE for the most recent years), and presented in earlier sections of this report. The simplest approach to evaluating a χ/Q would be to use a linear regression relationship of the air concentration and release rates to derive a value for χ/Q. However, as shown by Tables 3-10 and 3-11, the rank of the annual release estimate does not always coincide with the relative rank of the air concentration measured at Scarboro. For example, the highest ^{238}U air concentration (see Table 3-11) was measured in 1987, but the highest ^{238}U occurred in 1986. Of the 10 ^{238}U release estimates for 1986 - 1995, only one year matches the rank of the air concentration (1995). Similarly for $^{234/235}$U, only five of the ten years show the rank of the release quantities matching with the air concentrations.

Table 3-10: Rankings of Y-12 $^{234/235}$U Release Estimates Versus Rankings of Air Concentrations Measured at Scarboro

Year	$^{234/235}$U Annual Release		Scarboro Air Concentration		Do Rankings Match?
	Ci	Rank	fCi m^{-3}	Rank	
1986	0.349	2	0.62	2	YES
1987	0.592	1	1.10	1	YES
1988	0.302	3	0.60	3	YES
1989	0.148	4	0.38	4	YES
1990	0.080	5	0.24	6	**NO**
1991	0.039	6	0.17	7	**NO**
1992	0.037	7	0.26	5	**NO**
1993	0.030	9	0.11	8	**NO**
1994	0.032	8	0.05	9	**NO**
1995	0.018	10	0.03	10	YES

NOTE: Annual releases presented to 3 decimal places so as to establish rank

Table 3-11: Rankings of Y-12 ^{238}U Release Estimates Versus Rankings of Air Concentrations Measured at Scarboro

Year	^{238}U Annual Release		Scarboro Air Concentration		Do Rankings Match?
	Ci	Rank	fCi m^{-3}	Rank	
1986	0.0708	1	0.08	3	**NO**
1987	0.0496	2	0.16	1	**NO**
1988	0.0482	3	0.11	2	**NO**
1989	0.0025	6	0.05	4	**NO**
1990	0.0014	8	0.031	6	**NO**
1991	0.0065	5	0.029	7	**NO**
1992	0.0023	7	0.032	5	**NO**
1993	0.0010	9	0.018	8	**NO**
1994	0.0080	4	0.015	9	**NO**
1995	0.0006	10	0.01	10	YES

NOTE: Annual releases presented with 4 decimal places so as to establish rank

Such disparity in the ranks of releases and air concentration indicates that there is some uncertainty associated with the air measurements and/or release estimates. To account for these uncertainties, annual P/Q values were evaluated for each of the years under consideration (1986-1995). So as to maintain a larger sample size, and hence improve the statistical analysis of the empirical P/Q, independent values were calculated for both $^{234/235}$U and ^{238}U. These data points were then combined to generate a 20 value data set (Table 3-12).

Table 3-12: Empirical P/Q Values

Year	Radionuclide	Release Rate (pCi sec^{-1})	Air Concentration (pCi m^{-3})	Empirical P/Q (sec m^{-3})
1986	$^{234/235}U$	11,000	6.2×10^{-4}	5.6×10^{-8}
1986	^{238}U	2,300	7.8×10^{-5}	3.5×10^{-8}
1987	$^{234/235}U$	19,000	1.1×10^{-3}	5.9×10^{-8}
1987	^{238}U	1,600	1.6×10^{-4}	1.0×10^{-7}
1988	$^{234/235}U$	9,600	6.0×10^{-4}	6.3×10^{-8}
1988	^{238}U	1,500	1.1×10^{-4}	7.2×10^{-8}
1989	$^{234/235}U$	4,700	3.8×10^{-4}	8.0×10^{-8}
1989	^{238}U	80	5.2×10^{-5}	6.6×10^{-7}
1990	$^{234/235}U$	2,500	2.4×10^{-4}	9.4×10^{-8}
1990	^{238}U	50	3.1×10^{-5}	6.8×10^{-7}
1991	$^{234/235}U$	1,200	1.7×10^{-4}	1.4×10^{-7}
1991	^{238}U	210	2.9×10^{-5}	1.4×10^{-7}
1992	$^{234/235}U$	1,200	2.6×10^{-4}	2.2×10^{-7}
1992	^{238}U	70	3.2×10^{-5}	4.4×10^{-7}
1993	$^{234/235}U$	950	1.1×10^{-4}	1.2×10^{-7}
1993	^{238}U	30	1.8×10^{-5}	5.9×10^{-7}
1994	$^{234/235}U$	1,000	5.0×10^{-5}	4.9×10^{-8}
1994	^{238}U	250	1.5×10^{-5}	5.9×10^{-8}
1995	$^{234/235}U$	560	2.8×10^{-5}	5.0×10^{-8}
1995	^{238}U	18	1.1×10^{-5}	6.0×10^{-7}

NOTE: All values are rounded to two significant figures

Statistical analyses were then performed on the entire data set to estimate a measure of central tendency that could be used to represent the range of P/Q values (Table 3-13). Although tests for conformance of the data set with various distributions were inconclusive, for this application, the data were treated as if normally distributed. For estimating airborne contaminant concentrations at Scarboro due to direct releases from Y-12, the empirical P/Q value corresponding to the 95% upper confidence limit of the mean was used (3.1×10^{-7} s m^{-3}, which will be rounded to 3×10^{-7} s m^{-3}).

Table 3-13: Statistical Analysis of Empirical P/Q Values

Statistic	Empirical P/Q (sec m^{-3})
Mean	2×10^{-7}
Standard Deviation	2×10^{-7}
95^{th} UCL of the mean*	3×10^{-7}
Maximum	7×10^{-7}
Minimum	4×10^{-8}
Data Points	20

** 95 percent upper confidence limit of the mean for a normal distribution*

The 95th UCL value represents the upper confidence limit of the mean; whereby the true mean of the data lies below this value. The 95th UCL has been widely used for limited data sets for which a distribution cannot be determined. The use of distribution-free statistical methods(based on raw data) could have been used to determine the 95th UCL directly, however, given the limited number of data points and the range of values estimated, such an approach would have led to a value approaching the maximum estimated value.

The selected empirical P/Q value of 3×10^{-7} sec m^{-3} is independent of uranium isotope ($^{234/235}U$ or ^{238}U). This value was used directly with the release estimates presented in Section 2 of this report to estimate uranium air concentrations at Scarboro.

3.2.2.5 Predicted Air Concentrations from Past Y-12 Releases

Air concentrations for the Y-12 assessment were estimated for the Scarboro community situated about 1 km north of the Y-12 Plant. Air concentrations at the Scarboro community were evaluated for each year of release (1944-1995) based on the project team's estimates of airborne uranium releases from the Y-12 Plant and the empirical P/Q approach. Even though air concentrations at Scarboro were available for the period 1986 through 1995, the evaluated air concentrations using the empirical P/Q approach for these years were used so as to maintain consistency with prior years. Figure 3-6 presents air concentrations of $^{234/235}U$ and ^{238}U at the Scarboro community from Y-12 releases only. The annual average air concentrations at Scarboro are presented in Table 3-14 along with the range of values and the years corresponding to their release; tabulated air concentrations for all years are given in Table 3-15.

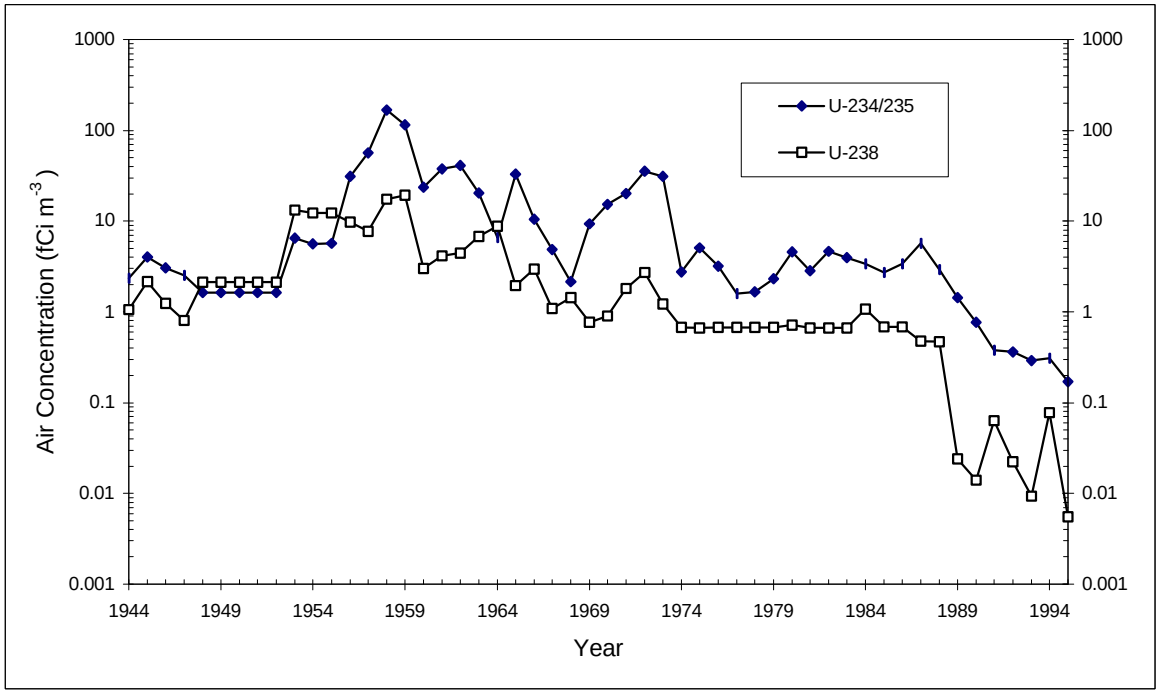


Figure 3-6: Estimated Annual Average Air Concentrations (fCi m^{-3}) at Scarboro from Y-12 Releases

Table 3-14: Estimated Annual Average Air Concentrations (fCi m^{-3}) at Scarboro from Y-12 Releases
Estimated Using the Empirical P/Q Approach

	$^{234/235}U$	^{238}U
Annual Average Air Concentration	15	3.1
Maximum Concentration (Release Year)	170 (1958)	19 (1959)
Minimum Concentration (Release Year)	0.17 (1995)	0.0055 (1995)

NOTE: All values are rounded to two significant figures

It is important to remember that the empirical P/Q approach is reliant upon Scarboro air concentration measurements, which are available only for the period 1986 to 1995, and release estimates for the same years. Differences in operations and release point distributions or characteristics for periods before 1986 could call into question the applicability of the empirical P/Q value to earlier years. In addition, information was gained late in the project that indicated that Y-12 uranium releases for some of the years used for development of the empirical P/Q value may have been understated due to omission of some unmonitored release estimates. It was not possible within the time frame of this project to evaluate the new data sufficiently to warrant its use in this assessment. If Y-12 uranium releases during years used to develop the empirical P/Q value applied in this assessment were indeed under reported, that would mean that the associated empirical P/Q values were overestimated, and concentrations at Scarboro that were estimated using that approach were in turn overestimated. It is impossible to gauge the magnitude of any biases potentially introduced by this possible under reporting without closely evaluating the bases of the release estimates during the associated years in the 1980s and 1990s.

Table 3-15: Estimated Average Air Concentrations (fCi m^{-3}) at Scarboro from Y-12 Releases
Estimated Using the Empirical P/Q Approach

Year	$^{234/235}U$	^{238}U
1944	2.4	1.1
1945	4.0	2.2
1946	3.0	1.3
1947	2.5	0.81
1948	1.6	2.1
1949	1.6	2.1
1950	1.6	2.1
1951	1.6	2.1
1952	1.6	2.1
1953	6.5	13
1954	5.6	12
1955	5.7	12
1956	31	10
1957	56	7.8
1958	170	17
1959	120	19
1960	24	3.0
1961	38	4.2
1962	41	4.5
1963	20	6.8
1964	6.5	8.8
1965	33	2.0
1966	11	3.0
1967	4.9	1.1
1968	2.2	1.4
1969	9.4	0.77
1970	15	0.91
1971	20	1.8
1972	36	2.7
1973	31	1.2
1974	2.7	0.67
1975	5.0	0.67
1976	3.2	0.67
1977	1.6	0.67
1978	1.7	0.67
1979	2.3	0.67
1980	4.6	0.71
1981	2.8	0.67
1982	4.7	0.66
1983	4.0	0.67
1984	3.4	1.1
1985	2.7	0.68
1986	3.4	0.69
1987	5.7	0.48
1988	2.9	0.47
1989	1.4	0.024
1990	0.77	0.014
1991	0.38	0.063
1992	0.36	0.022
1993	0.29	0.0093
1994	0.31	0.078
1995	0.17	0.0055

NOTE: All values are rounded to two significant figures

3.3 Uranium Concentrations in Surface Water

There are two principal sources of surface water that could conceivably present complete exposure pathways for inclusion in this screening assessment. East Fork Poplar Creek (EFPC) flows from the Y-12 site, within about 0.4 mile of the Scarboro community, and westward to its confluence with Poplar Creek. EFPC represents the most credible source of surface water exposure for the Scarboro resident. The other major surface water source is the Clinch River, which runs along much of the western, southern, and eastern boundaries of the ORR. Reference locations for K-25/S-50 and X-10 are both in close proximity to the Clinch River. The Clinch River was considered a source of water-based recreational exposure and as the source of fresh fish. Exposure durations and fish consumption rates were higher than those used for the Y-12 and combined assessments, as the Clinch River was better suited to water-based recreational activities than was EFPC and could support larger fish populations.

Surface water concentrations of uranium in EFPC were retrieved from Y-12 Health Physics and Accountability reports that contained uranium release estimates and flow rate data for EFPC. Flow rates and concentrations in the Creek were determined based on a weir-based flow measurement system and a continuous, flow-proportional composite sampler on EFPC and New Hope Pond. A diagram of this flow measurement and sample collection system is presented in Appendix C. Annual waterborne release estimates reported in Y-12 Health Physics and Accountability records were based, in part, on water samples collected with this sampling system (West[1] 1958; Sanders 1958; Owings 1986, 1996).

Annual average uranium concentrations in EFPC for 1944 to 1991 were derived by dividing the annual average release rate (Owings 1986; Woltman 1996) by the EFPC annual flow rate of 2,920 million gallons per year (8 gallons per day times 365 days per year). No data were available for 1992 through 1995, therefore it was assumed that the concentrations in EFPC for these years was the same as those for 1991. From the 1944-1995 data, an average uranium concentration over 1944–1995 was calculated for use in the Task 6 screening assessment (Table 3-16).

Reported annual average uranium concentrations in Clinch River water were used for the Task 6 screening evaluation. Clinch River data were reported as average annual concentrations ($\mu Ci\ mL^{-1}$). These values were derived by K-25 personnel based on water samples collected at the confluence of Poplar Creek and the Clinch River. Data were compiled by the project team from K-25 Industrial Hygiene and DOE Environmental Monitoring Reports for all years of operation. In most cases, only the total uranium activity was measured. To partition these concentrations by isotope, it was assumed that both the EFPC and the Clinch River surface water concentrations were natural uranium. Using the specific activity of each uranium isotope, along with the natural abundance of each isotope, $^{234/235}U$ and ^{238}U concentrations were calculated. Total uranium (mass) concentrations were calculated based on the calculated specific activity for natural uranium. The concentrations of uranium in surface water used for this assessment are presented in Table 3-16 for EFPC and Table 3-17 for the Clinch River.

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[1]Personal communication between Charles (Hap) West and Bill Tucker (former Y-12 health physics workers) and the Task 6 project team.

Table 3-16: Uranium Concentrations in East Fork Poplar Creek

	Total Uranium (pCi L^{-1})	^{238}U (pCi L^{-1})	$^{234/235}U$ (pCi L^{-1})	Uranium (mg L^{-1})
1944	2100	1000	1100	3.0
1945	450	210	240	0.63
1946	450	210	240	0.63
1947	450	210	240	0.63
1948	99	47	52	0.14
1949	290	140	150	0.41
1950	9.1	4.3	4.8	0.013
1951	6.2	2.9	3.3	0.0088
1952	0.0070	0.0033	0.0037	0.000010
1953	61	29	32	0.085
1954	71	34	37	0.099
1955	68	32	36	0.095
1956	320	150	170	0.45
1957	540	260	280	0.76
1958	640	300	340	0.89
1959	660	320	350	0.93
1960	640	300	340	0.90
1961	200	93	100	0.27
1962	14.8	7.0	7.8	0.021
1963	80	38	42	0.11
1964	420	200	220	0.59
1965	570	270	300	0.79
1966	510	240	270	0.71
1967	970	460	510	1.4
1968	1100	530	590	1.6
1969	270	130	140	0.38
1970	560	270	290	0.79
1971	230	110	120	0.32
1972	190	92	100	0.27
1973	71	34	37	0.099
1974	99	47	52	0.14
1975	104	50	55	0.15
1976	87	42	46	0.12
1977	48	23	25	0.067
1978	26	12	14	0.036
1979	23	11	12	0.033
1980	9.9	4.7	5.2	0.014
1981	44	21	23	0.062
1982	54	25	28	0.075
1983	110	54	60	0.16
1984	110	54	60	0.16
1985	50	24	26	0.070
1986	42	20	22	0.058
1987	42	20	22	0.058
1988	42	20	22	0.058
1989	42	20	22	0.058
1990	42	20	22	0.058
1991	42	20	22	0.058
1992*	42	20	22	0.058
1993*	42	20	22	0.058
1994*	42	20	22	0.058
1995*	42	20	22	0.058
EFPC average concentration (1944-1995)		**121**	**134**	**0.36**

** Values not available: assume same concentration as last reported year (1991)*
NOTE: All values are rounded to two significant figures

Table 3-17: Uranium Concentrations in the Clinch River

	Total Uranium (pCi L^{-1})	^{238}U (pCi L^{-1})	$^{234/235}U$ (pCi L^{-1})	Uranium (mg L^{-1})
1944	0.0	0.0	0.0	0.0
1945	0.0	0.0	0.0	0.0
1946	0.0	0.0	0.0	0.0
1947	1.0	0.47	0.53	0.0014
1948	1.0	0.47	0.53	0.0014
1949	1.6	0.76	0.84	0.0023
1950	1.6	0.76	0.84	0.0023
1951	0.0012	0.00057	0.00063	0.0
1952	4.5	2.1	2.4	0.0063
1953	4.5	2.1	2.4	0.0063
1954	2.3	1.1	1.2	0.0032
1955	12	5.7	6.3	0.017
1956	79	38	42	0.11
1957	25	12	13	0.035
1958	27	13	14	0.038
1959	20	9.5	11	0.028
1960	16	7.6	8.4	0.022
1961	54	26	28	0.076
1962	13	6.2	6.8	0.018
1963	14	6.6	7.4	0.019
1964	12	5.7	6.3	0.017
1965	15	7.1	7.9	0.021
1966	15	7.1	7.9	0.021
1967	15	7.1	7.9	0.021
1968	15	7.1	7.9	0.021
1969	15	7.1	7.9	0.021
1970	15	7.1	7.9	0.021
1971	21	10	11	0.029
1972	4.0	1.9	2.1	0.0056
1973	4.0	1.9	2.1	0.0056
1974	21	10	11	0.029
1975	10	4.7	5.3	0.014
1976	14	6.6	7.4	0.019
1977	6.1	2.9	3.2	0.0084
1978	4.0	1.9	2.1	0.0056
1979	5.0	2.4	2.6	0.0070
1980	4.0	1.9	2.1	0.0056
1981	6.1	2.9	3.2	0.0084
1982	3.0	1.4	1.6	0.0042
1983	4.0	1.9	2.1	0.0056
1984	7.0	3.3	3.7	0.0098
1985	8.0	3.8	4.2	0.011
1986	8.0	3.8	4.2	0.011
1987	9.0	4.3	4.7	0.013
1988	7.0	3.3	3.7	0.0098
1989	7.0	3.3	3.7	0.0098
1990	7.0	3.3	3.7	0.0098
1991	7.0	3.3	3.7	0.0098
1992*	7.0	3.3	3.7	0.0098
1993*	7.0	3.3	3.7	0.0098
1994*	7.0	3.3	3.7	0.0098
1995*	7.0	3.3	3.7	0.0098
Clinch River average concentration (1944-1995)		**5.2**	**5.8**	**0.015**

** Values not available: assume same concentration as last reported year (1991)* *NOTE: All values are rounded to two significant figures*

3.4 Uranium Concentrations in Soils

Soil concentrations used for the screening assessment were those measured at locations nearest the Task 6 reference locations. Values were taken from the report of Tasks 3 and 4 of the Dose Reconstruction Feasibility Study (ChemRisk 1993b) and ORR environmental monitoring reports. In the absence of soil data, concentrations in sediments were used, since exposure to sediments may occur as a result of dredging and subsequent use of dredge soils as fill material (ChemRisk 1993b).

Soil or sediment values were chosen from locations close to each reference location. For the X-10 assessment, the location was along the Clinch River between the entrances of White Oak Creek and Poplar Creek (Cook et al. 1992). This span includes the area of Jones Island, the reference location for X-10. For the K-25/S-50 assessment, values were selected from along the Clinch River between the entrance of Poplar Creek and the confluence with the Tennessee River (Cook et al. 1992). This corresponds well with the K-25/S-50 reference location.

Soil data for Y-12 were taken from surface measurements in the EFPC floodplain between New Hope Pond and EFPC Mile 8.8 (Hibbitts 1984), near the reference location for Y-12 exposures. The reference cited by Hibbitts includes a report prepared by C. S. Gist (Oak Ridge Associated Universities). The Y-12 values used for this assessment differ from the values reported in the report of Tasks 3 and 4 of the Dose Reconstruction Feasibility Study (ChemRisk 1993b), as the concentration of ^{234}U is assumed to be in secular equilibrium with ^{238}U. As a result, the concentration of ^{234}U is equal to the concentration of ^{238}U. Therefore, the $^{234/235}U$ concentration is the sum of the value reported for ^{235}U (5,900 pCi/kg) and the assumed secular equilibrium value for ^{234}U (70,000 pCi/kg). A second set of concentrations was developed for use in the Level II screening assessment. The data used by Hibbitts and Gist (Hibbitts 1984) were analyzed, and the mean concentrations for $^{234/235}U$ and ^{238}U were evaluated. The reported average uranium concentration (26 ppm or 26 mg kg^{-1}) was converted into activity concentrations of the uranium isotopes by assuming the relative concentrations of the isotopes were equal to their natural abundances (see Table 3-18).

Table 3-18: Selected Measurements of Uranium in Soil or Sediment near Task 6 Reference Locations and Concentrations Derived from Them
(Bold values are as reported; remaining values were derived from the reported values)

Complex	Screening Assessment	$^{234/235}U$ (pCi kg^{-1})	^{238}U (pCi kg^{-1}) *(^{234}U is equal)*	^{235}U (pCi kg^{-1})	Total Uranium (mg kg^{-1})
Y-12	Level I	76,000	**70,000**	5,900	NA
Y-12	Level II	14,000	12,000	2,000	**26**
K-25/S-50*	Level I/II	**6,200**	**4,000**	2,200	NA
X-10	Level I	**2,100**	**1,800**	300	NA

** Limited available data to the project team prevented the use of different values for Level I and II*
NOTES: All values are rounded to two significant figures, if applicable. NA = Not Available.

As noted earlier, the concentrations of ^{234}U and ^{235}U were not segregated for the assessment of exposures via air and water pathways. The relative doses received internally after ^{234}U and ^{235}U are inhaled or ingested do not differ significantly due to the similarity in their dose conversion factors. However, when considering external doses received from radionuclide concentrations in soil, there are significant differences between the ^{234}U and ^{235}U dose factors. To account for these differences in the dose assessment, it was necessary to characterize the relative abundances of these two radionuclides.

For the Y-12 assessment, the Level I screening assessment assumed that ^{234}U was in secular equilibrium with its parent, ^{238}U. Since the reported concentration of ^{238}U equaled 70,000 pCi/kg, the ^{234}U concentration was assumed to also be equal to 70,000 pCi/kg. The concentration of ^{235}U in soil for the Level I assessment was 5,900 pCi/kg, which is the concentration reported by Hibbitts (Hibbitts 1984). The mean uranium concentration in terms of parts per million (ppm) of uranium was converted into activity concentrations by assuming the relative concentrations of the isotopes were equal to their natural abundances. Thus, the $^{234/235}U$ concentration of 14,000 pCi/kg is assumed to be composed of 12,000 pCi/kg of ^{234}U and 2,000 pCi/kg of ^{235}U.

A similar approach was used to determine the relative abundance of ^{234}U and ^{235}U for the Level I K-25/S-50 assessment. The reported concentration of ^{238}U equals 4,000 pCi/kg, and the ^{234}U concentration is assumed to also be equal to 4,000 pCi/kg. Therefore, the concentration of ^{235}U in soil for the K-25/S-50 assessment is the reported concentration for $^{234/235}U$ of 6,200 pCi/kg minus the 4,000 pCi/kg assumed for ^{234}U, to give a ^{235}U concentration of 2,200 pCi/kg.

Special Considerations Regarding Scarboro Soil Concentrations

The Level I assessment used highly conservative uranium soil concentrations due to the limited nature and uncertainty of the data that are available to the project team. The project team used these values recognizing the need to ensure that the assessment did not underestimate potential exposures that occurred over the last 45+ years. The Level I assessment used maximum uranium concentrations measured in soil/sediment samples from the EFPC floodplain from studies conducted in the 1980s.

The second level of screening was considerably less conservative than the Level I analysis; less conservative "Level II" values were used for various exposure parameters (consumption rates, fractions of foods contaminated, etc.) than were used in the Level I screening assessment. The goal in Level II assessments is to remove known sources of conservative bias. For soil concentrations, an average value was used in Level II compared to a maximum measured value used for the Level I assessment. Because of the scarcity of information regarding estimates of uranium concentrations in the environment over the period of interest, some conservatism was maintained in the uranium concentration estimates used in Level II screening to ensure that hazards to a significant portion of the potentially exposed population were not underestimated. Conservatism was probably also introduced by the use of 1980 EFPC floodplain measurements to represent concentrations at Scarboro, which is outside of the floodplain. As such, the second level of screening may be more appropriately called a Refined Level I analysis. The data that are currently available are not sufficient to support a defensible analysis of average or typical exposures to members of the Scarboro community from the community's inception to the present.

A significant factor in the decision to maintain a conservative value of soil concentration in Level II screening was the uncertainty concerning the level of ^{235}U enrichment in the soil represented by the value of 26 ppm total uranium. Because of this uncertainty, the concentration corresponding to 14,000 pCi kg^{-1} $^{234/235}U$ (or 26,000 pCi kg^{-1} total uranium) was used. To illustrate how the overall results of the assessment would differ if lower soil concentrations were assumed, screening indices were also calculated for soil concentrations of 7,000 and 2,000 pCi kg^{-1} total uranium. Lacking isotopic ratio information, it was assumed that the 7,000 and 2,000 pCi kg^{-1} values represented natural uranium. This discussion gives the reader an indication of how the overall results of the assessment would change if less conservative estimates of soil concentration were used.

4.0 ASSESSMENT OF URANIUM SCREENING INDICES FROM PAST RELEASES

Once concentrations of uranium were estimated at the reference locations, the logical next step was to evaluate the potential significance of those concentrations. This was done by estimating the radiation doses that could have been received by off-site populations and the total quantities (masses) of uranium that they could have taken into their bodies. Radiation dose estimates can then be translated into screening indices, and uranium intakes were used to estimate levels of uranium metal that might have been present in the kidneys; the main target organ for assessing potential deterministic effects from uranium exposures. These body burdens were compared to published data that indicate the levels above which uranium, as a toxic heavy metal, can start to cause adverse health effects in exposed individuals. These approaches represent a conservative estimation of the potential health effects associated with past uranium releases.

This screening assessment evaluates the potential health effects to the individuals that have lived in areas surrounding the ORR from the releases of uranium from the Y-12, K-25/S-50 and X-10 facilities. Due to the distances between these facilities, independent assessments were conducted for each site. Reference locations were selected based on areas that were inhabited during the operational phases of the facilities, and on the proximity of these locations to the points of release. By employing established exposure assessment methods, estimates of material intake were made for individuals living at these reference locations.

SCREENING INDICES

The screening indices represent estimates of the potential human health impacts from the releases estimated for the three complexes. The screening indices are compared to the decision guide established by Oak Ridge Health Agreement Steering Panel (ORHASP) to determine if further work to estimate the human health risks from past uranium releases is warranted.

4.1 Screening Methodology

The screening methodology used in this assessment employed a two tiered approach to assessing screening indices (ChemRisk 1996). The Level I assessment was used to assess health impacts to the maximum exposed individual, and the Level II assessment represents a less conservative, typical individual. For the Level II assessment, known sources of conservative bias in the Level I assessment were eliminated if adequate information was available during the Task 6 investigation. The purpose of the Level I screening was to identify the uranium release sources and exposure pathways that do not warrant detailed investigation (that is, those that yielded screening indices that fell below the decision guide). The purpose of the Level II screening was to identify which, if any, of the release sources and exposure pathways that appeared to be potentially important from Level I screening should be given high priority for detailed investigation (that is, those that yielded Level II screening indices above the decision guide).

4.1.1 Level I Screening

The Level I assessment addressed an individual with the highest potential for exposure to the releases; this is generally regarded as the maximally exposed individual. The Level I screening assumes higher exposure frequencies to the releases as well as higher consumption rates for produce raised in the contaminated environment. The intake for produce raised at the reference location represents the upper bound both in terms of daily intake as well the fraction of meat, milk, and vegetables that are raised in the contaminated environment.

4.1.2 Level II Screening

The Level II screening is designed to estimate the screening index for an average or more typically exposed individual. The Level II analysis was performed for those releases that produced a screening index that exceeded the decision guide using the Level I approach. Exposure frequencies were assumed to be equal to 350 days per year to account for a period of two weeks per year away from the reference location. The fraction of consumables that are contaminated was significantly lower than the Level I screening, to account for the fact that the typical individual will rely (at least in part) on outside sources for produce. Since the Task 6 source term assessments for air and water releases did not include formal uncertainty analyses, the Level I and II screening used the same release estimates as the basis for completing the exposure evaluations. Except for the Scarboro/Y-12 assessment, the Level I and II screening for K-25/S-50 used the same estimates of uranium concentrations in soil due to the limited data available to the project team.

4.2 Exposure Assessment

The exposure assessment considered a series of exposure pathways and material transport mechanisms to quantify the extent to which an individual at a reference location was exposed to uranium released to the environment. Exposure is presented in terms of the quantity of material that is either inhaled or ingested over a given time frame. For uranium, the exposure assessment also included external exposures from radionuclides in soil and water. The exposure assessment accounted for both the time that the hypothetical exposed individual spent in an exposed environment, as well as the quantity of produce raised in the exposed environment that he or she consumed. The results of the exposure assessment can be used to estimate screening indices for potentially exposed individuals. For this screening study, the exposure assessment quantified the extent of exposure from the releases of uranium from the Y-12, K-25/S-50 and X-10 facilities. Exposures are based on the three contaminated media: soil, water and air. Intakes of uranium present in these three media were estimated based on the applicable pathways of exposure. Typical pathways include the inhalation of contaminated air, the ingestion of fish caught in contaminated water, and the ingestion of milk from cows raised on contaminated soil.

4.2.1 Reference Locations

Due to the distances between the Y-12, K-25/S-50 and X-10 facilities, three distinct reference locations were used for the exposure assessment. These reference locations represent the closest point from the facility of interest at which residents were expected to have lived. Factors such as patterns of habitation for the duration of the releases, as well as the presence of present day communities were used to select the reference location for the screening assessment. Selection of these reference locations was discussed in Section 3 of this report; all three reference locations were described in Section 3.1.

For each reference location, the exposure assessment was based on complete exposure pathways from air, soil, and water. Pathways represent mechanisms and routes by which the materials can come in contact with the exposed individual. Some of these pathways are direct, such as the inhalation of contaminated air, while others require significantly complex modeling. Complex models are used to assess the intake through multiple intermediate media, such as the intake of beef from cattle grazing on pasture contaminated by the deposition of airborne materials. The pathways addressed for each of the three media are described below.

4.2.2 Air Exposure Pathways

Air releases were estimated at the selected reference locations using either atmospheric dispersion modeling or an empirical P/Q approach. A discussion of these assessment methods was presented in Section 3. The estimated concentrations of uranium in air were used in units of pCi m^{-3} or mg m^{-3}. From these concentrations, exposures via inhalation, ingestion, or direct external radiation were evaluated for the pathways described in Table 4-1.

Table 4-1: Air Exposure Pathways Evaluated in the Screening Analysis

Air Pathways	Exposure Route
Air to Humans - Direct Inhalation of Airborne Particulates Inhalation of contaminants in air that were released from the facility and were transported to the reference location. Exposure assessment accounts for the time an individual spent at the reference location as well as the time spent indoors, where the concentration is lower.	Inhalation
Air to Humans (Immersion in contaminated air) An individual located within the plume of air releases will be subject to external radiation from the uranium suspended in the atmosphere.	External
Air to livestock (via inhalation) to beef to humans Cattle located at the reference location will also inhale uranium suspended in air that originated from the facility. This material, once inhaled, will transfer to the consumable portions of cattle (meat) via transfer fractions that account for the biokinetics of the cow. Uranium will accumulate over time, and will be ingested by the exposed individual once the cattle is harvested for consumption.	Ingestion

Table 4-1: Air Exposure Pathways Evaluated in the Screening Analysis *(continued)*

Air to dairy cattle (via inhalation) to milk to humans Similar to the air to livestock (inhalation) to beef to humans via ingestion pathway, bio-accumulation of uranium can also occur in milk from uranium inhaled by dairy cattle.	Ingestion
Air to vegetables (deposition) to humans Uranium released to the air and transported to the reference location will eventually deposit onto vegetation that can be consumed. Generally, some of this material is removed by washing, however, a fraction of the deposited uranium will be present when the vegetables are consumed.	Ingestion
Air to pasture (deposition) to cattle beef to humans Similar to the deposition of materials onto vegetables from uranium released to the air, deposition will also occur onto pasture that is consumed by both beef and dairy cattle. Unlike the air to vegetables pathways, there is no removal by washing. Once the uranium is ingested by the cattle, it will transfer to the consumable portions of beef cattle where it will accumulate until the cattle is harvested for consumption.	Ingestion
Air-pasture (deposition) to dairy cattle to milk to humans This pathway is similar to the air to pasture (deposition) to cattle beef to humans via ingestion pathways, with the exception that uranium accumulation and consumption is via milk from dairy cows.	Ingestion

4.2.3 Water Exposure Pathways

Water pathways in this assessment represent the routes of exposure for waterborne uranium in the two primary surface water sources: East Fork Poplar Creek (EFPC) for the Scarboro reference location and the Clinch River for the Union/Lawnville and Jones Island reference locations. Concentrations for EFPC were evaluated based on release estimates, and on the flow rates measured close to the point of release. Uranium concentrations in the Clinch River used for this analysis were reported annual average concentrations. Concentrations measured as ($pCi\ L^{-1}$) or ($mg\ L^{-1}$) were used to estimate exposure via the pathways described in Table 4-2.

Table 4-2: Water Exposure Pathways Evaluated in the Screening Analysis

Water Pathways	Exposure Route
Incidental Ingestion by humans during recreation Although the direct consumption of surface water is not a credible pathway, incidental ingestion of river water may have occurred during recreational activities such as swimming. This pathway is used to evaluate the quantity of waterborne uranium ingested via incidental ingestion of surface water. The exposure accounts for the limited amount of time that a exposed individual will be in the river, as well as the number of times per year that a person will use the river for recreational purposes.	Ingestion
Water to livestock (ingestion) to beef to humans Surface water may have been used to water farm animals such as beef and dairy cattle. As is the case with all cattle pathways, a fraction of the waterborne uranium ingested by cattle will transfer to the consumable portion of the cow.	Ingestion
Water to dairy cattle (ingestion) to milk to humans As is the case with the water to livestock (ingestion) to beef to humans via ingestion pathway, uranium ingested from surface water will accumulate in milk.	Ingestion
Water to fish to humans Both surface water bodies considered here (East Fork Poplar Creek and the Clinch River) are sources of consumable fish. Fish raised in contaminated water will accumulate uranium over time within the edible portion of the fish. This pathway evaluates the intake of uranium by the ingestion of fish caught in the two surface water bodies considered.	Ingestion
Water to humans via immersion during recreation During recreational use of the surface water bodies, the exposed individual is likely to receive an external dose from the waterborne uranium. As an incidental ingestion pathway, this exposure route is limited by the time spent immersed in surface water	External

4.2.4 Soil Exposure Pathways

Measured uranium soil concentrations were compiled from a number of sources. These sampling locations could not always be co-located with the reference locations; for the screening assessment, concentrations closest to the reference location were used. Measured concentrations were presented in units of pCi kg^{-1} or mg kg^{-1}. From these concentrations, the exposure was quantified for the pathways described in Table 4-3.

Table 4-3: Soil Exposure Pathways Evaluated in the Screening Analysis

Soil Pathways	Exposure Route
Soil to air (dust resuspension) to humans The resuspension of dust occurs by either wind driven forces or by the mechanical disturbance of surface soils. Since the uranium will be attached to soil, this means that the contaminants will be resuspended and can be inhaled.	Inhalation
Soil incidental ingestion Incidental soil ingestion occurs through a variety of mechanisms, including the ingestion of resuspended dust and the ingestion of material that accumulates on the hands and fingers of an individual. This pathway quantifies the amount of contaminated soil that is incidentally ingested.	Ingestion
Soil to livestock (soil ingestion) to beef to humans via ingestion Soil is ingested by cattle as part of their grazing activities. As was the case for all other cattle pathways, the ingested material will transfer to the edible portions of cattle.	Ingestion
Soil to dairy cattle (soil ingestion) to milk to humans Similarly for dairy cattle, material associated with ingested soil will accumulate in milk.	Ingestion
Soil to vegetables (root uptake) to humans Uranium in soil will translocate through the root into vegetation. The uptake of uranium is represented by a bio-accumulation factor that is a ratio of the concentration of uranium in plants to that in soil. Ingestion of vegetation grown in contaminated soil can be a major pathway for exposure via ingestion if the bio-accumulation potential for the material is high.	Ingestion
Soil to pasture (root uptake) to livestock to beef to humans The translocation of uranium from soil to vegetation is also of concern when considering pasture that is consumed by cattle. Contaminated pasture is consumed by cattle, and uranium will bio-accumulate in the consumable portion of the cow. This pathway requires multiple sub-models: these include the translocation of uranium to pasture, the consumption of pasture by cattle, the accumulation of uranium into the consumable portion of the cattle, and finally the consumption of the beef by the exposed individual.	Ingestion
Soil to pasture (root uptake) to dairy cattle to milk to humans A similar number of sub-models exist for the transfer of material from soil to pasture to dairy cattle, to milk and eventually to humans. This pathway is analogous to soil to pasture (root uptake) to livestock to beef to humans via ingestion, however, different transfer fractions are used for the accumulation of uranium in milk, and for the quantity of milk ingested per day.	Ingestion
Soil to humans via external radiation Uranium present in soil will emit penetrating radiation according to its nuclear characteristics. This pathway quantifies the doses to individuals from the penetrating radiation emitted from uranium isotopes in soil.	External

A series of models were used to estimate intake from these pathways. These equations are consistent with those that have been developed by various regulatory agencies for evaluating exposures to chemicals and radionuclides (USEPA 1979; NCRP 1991; USEPA 1988). These models are used to estimate the intake of uranium by the three modes of exposure: inhalation, ingestion and direct radiation exposure. The equations used are presented in Appendix J and are used to estimate either intake via inhalation or ingestion, or direct exposure to uranium. Each equation yields results in units of either picocurie per day (pCi d^{-1}) or milligrams per day (mg d^{-1}).

4.2.5 Exposure Assessment Parameters

Two sets of exposure assessment parameters were used to quantify uranium intake by exposed individuals. These sets correspond to the two levels of screening assessment defined previously (Level I and Level II). Exposure parameters quantify the magnitude of exposure; there are generally six types of exposure parameters:

- intake of consumables (meat, milk, vegetables, fish),
- incidental intake of soil and incidental ingestion of surface water during recreational activities,
- the fraction of time spent within the contaminated environment,
- physiological parameters such as breathing rates,
- parameters for livestock, including breathing rates, pasture consumption, water intake, incidental soil intake, and
- foliar deposition parameters for vegetation, including interception fractions, deposition velocities, and weathering rates.

All the parameters used for both assessments (Level I and Level II) are presented in Appendix K, along with the rationales for selection of values.

Bio-transfer factors are used to estimate the fraction of a contaminant that is transferred from the environmental media to products that are consumed. These factors are used to estimate concentrations in meat, milk, vegetation, and fish. Factors required for exposure assessment include:

- Concentration ratio for the transfer of contaminant from soil to vegetation,
- Concentration ratio for the transfer of contaminant from soil to pasture,
- Biotransfer factor for contaminant inhaled or ingested by cattle to meat,
- Biotransfer factor for contaminant inhaled or ingested by cattle to milk, and
- Bio-concentration factor for uranium in fish.

As these values are dependent upon the transferability of the materials of concern, these values are element specific. The bio-transfer factors for uranium used for this assessment are presented in Table 4-4.

Table 4-4: Bio-Transfer and Accumulation Factors for Uranium

Bio-Transfer Factor		Unit	Value	Reference
$B_{(veg)}$	Concentration ratio for the transfer of uranium from dry soil to vegetables (wet wt.)	unitless	1.2×10^{-2}	(IAEA 1994). Converted to wet weight by dividing by factor of 7 as recommended.
$B_{(pasture)}$	Concentration ratio for the transfer of uranium from dry soil to pasture (dry wt.)	unitless	1.0×10^{-1}	NCRP Report No. 123 (NCRP 1996)
F_m (s/p)	Biotransfer factor from cattle intake (soil and pasture) to milk	d L^{-1}	4.0×10^{-4}	NCRP Report No. 123 (NCRP 1996)
F_f(s/p)	Biotransfer factor from cattle intake (soil and pasture) to meat	d kg^{-1}	8.0×10^{-4}	NCRP Report No. 123 (NCRP 1996)
F_m(w)	Biotransfer factor from cattle intake (water) to milk concentration	d L^{-1}	4.0×10^{-4}	Assume same as Biotransfer from Soil
F_f(w)	Biotransfer factor from cattle intake (water) to meat concentration	d kg^{-1}	8.0×10^{-4}	Assume same as Biotransfer from Soil
BCF	Bio-concentration factor for fish	(mg kg^{-1})/ (mg L^{-1})	10	NCRP Report No. 123 (NCRP 1996)

4.3 Calculation of Radionuclide Screening Indices

To convert uranium intake estimated by the exposure assessment to a screening index, the intake was first converted to a radiation dose using dose conversion factors (DCFs). These factors are radionuclide specific, and represent a committed effective dose equivalent (CEDE) per unit intake. DCFs are also specific to the route of exposure; values for inhalation, ingestion and external exposure for each of the radionuclides considered were used. For inhalation and ingestion DCF values, the latest recommendations of the ICRP (International Commission on the Radiological Protection) were used. Recent improvements in the characterization of radionuclide kinetics in the body, and the use of improved internal dosimetry models, have lead to the issuance of a new set of dose conversion factors for members of the public. These new DCF values for uranium have been used for this assessment.

The inhalation and ingestion DCFs for ^{234}U and ^{235}U, as recommended by the ICRP, are similar in magnitude. Hence the selection of either DCF (^{234}U or ^{235}U) has very little effect upon the resultant dose from the inhalation and ingestion pathways. For doses received from exposure to radiation from radionuclides to soil, the $DCF_{external\text{-}soil}$ differs by orders of magnitude; the value for ^{235}U is almost 2,000

times greater than that for ^{234}U. To account for this variation in $DCF_{external\text{-}soil}$ a composite $DCF_{external\text{-}soil}$ was derived based on the relative abundances of the two radionuclides (^{234}U and ^{235}U) in soil. The relative abundances for each radionuclide were previously discussed and quantified in Section 3.4. The five DCFs for each of the uranium isotopes are presented in Table 4-5. The two values for $DCF_{external\text{-}soil}$ are also presented in Table 4-5.

Table 4-5: Uranium Dose Conversion Factors (DCFs)

DCF	Exposure	$^{234/235}U$	^{238}U	Notes
$DCF_{Inhalation}$	DCF for uranium isotope inhaled (Sv Bq^{-1})	9.4×10^{-6}	8.0×10^{-6}	1, 4, 6
$DCF_{Ingestion}$	DCF for uranium isotope ingested (Sv Bq^{-1})	4.9×10^{-8}	4.5×10^{-8}	2, 5, 6
$DCF_{imm\text{-}air}$	External DCF for immersion in contaminated air (Sv m^3)/(Bq y)	2.27×10^{-7}	1.08×10^{-10}	3
$DCF_{Imm\text{-}water}$	External DCF for immersion in contaminated water (Sv m^3)/(Bq y)	5.01×10^{-10}	2.51×10^{-13}	3
$DCF_{external\text{-}soil}$	External Dose conversion factor for exposure to radiation from radionuclides in soil. (Sv m^3)/(Bq y)	^{234}U: 6.75×10^{-14} ^{235}U: 1.18×10^{-10}	1.74×10^{-14}	3, 7, 8

Notes:

1. *ICRP Publication 72 (ICRP 1996)*
2. *ICRP Publication 71 (ICRP 1995)*
3. *Federal Guidance Report 12 (USEPA 1993)*
4. *Inhalation absorption rate classified as Type S: particulate size specified as 1 AMAD (Activity Median Aerodynamic Diameter)*
5. *Ingestion transfer fraction f_1=0.02 (fraction of contaminant ingested that is transferred to the blood stream from the gastrointestinal tract)*
6. *^{234}U used to represent $^{234/235}U$ DCF (highest value)*
7. *A composite $DCF_{external\text{-}soil}$ was calculated based on the relative abundances of ^{234}U and ^{235}U*
8. *External DCF for uranium for contaminant in soil to a depth of 15 cm.*

Converting doses in sieverts (Sv) to screening indices was achieved using a dose-to-risk coefficient of 7.3% Sv^{-1}. This value is consistent with the recommendations of ICRP Publication 60 (ICRP 1990), and is consistent with the dose conversion factors listed above in Table 4-5. Doses evaluated for each pathway were converted to screening indices by multiplying the dose in sieverts by 0.073. The screening index calculation for each exposure pathway can be represented by the following equation:

$$Radionuclide\ Screening\ Index_i = INTAKE_i \times EF \times ED \times Cf_1 \times DCF_i \times 0.073$$

Where:

$Radionuclide\ Screening\ Index_i$	=	radionuclide screening index from pathway i
$INTAKE_i$	=	daily intake through pathway i (pCi d^{-1})
EF	=	exposure frequency (d y^{-1})
ED	=	exposure duration (y)
Cf_1	=	conversion factor (Bq pCi^{-1})
DCF_i	=	dose conversion factor for pathway i (Sv Bq^{-1})
0.073	=	dose to risk coefficient (Sv^{-1})

4.4 Summary of Screening Indices

Based on the concentrations of uranium isotopes estimated in the three environmental media (air, water, and soil) and the methodology of evaluating screening indices presented above, the screening indices for the three assessments were estimated.

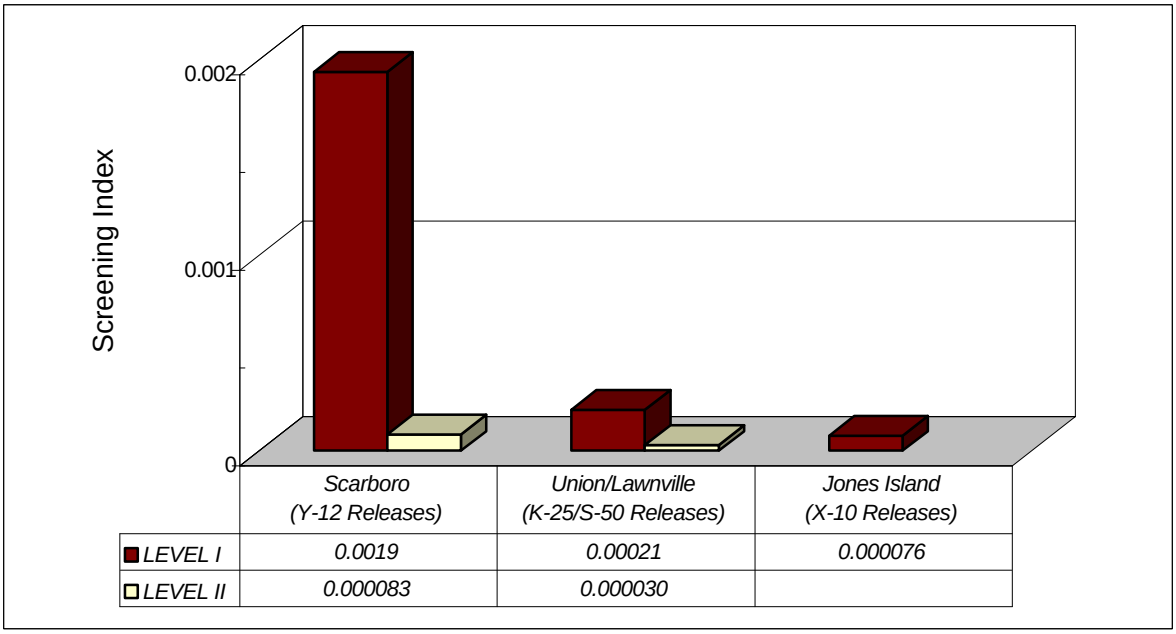
Screening indices calculated for each pathway were summed to estimate a total screening index for each reference location from each uranium isotope of concern. Screening indices for $^{234/235}U$ and ^{238}U were then summed to generate a total screening index. Where exposure parameters varied as a function of the age of the individual, values that are representative of the adult age group were selected. The initial approach for the Task 6 screening was to evaluate screening indices for adults living at each reference location. If these indices did not exceed the project decision guide (1×10^{-4} cancer risk) over all pathways, then indices for children would be evaluated, since children are more radiosensitive. As discussed later in this section, estimated screening values for adults did exceed the decision guide, and therefore evaluations for other age groups were not performed. As previously mentioned, these screening results are not intended to be used as a measure of true risks incurred by nearby residents. Rather, the screening indices are for use in evaluating if further study of potential health effects from past uranium releases is warranted.

A summary of the uranium screening indices calculated for the Scarboro, Union/Lawnville, and Jones Island assessments is presented in Table 4-6. These indices were summed across all media of exposure (air, water and soil) and for both uranium isotopes ($^{234/235}U$ and ^{238}U). Figure 4-1 shows the relative magnitude of the screening indices calculated for each complex. Detailed analysis of the total screening indices for the Scarboro, Union/Lawnville, and Jones Island assessments are presented in Sections 4.5, 4.6, and 4.7, respectively.

Table 4-6: Summary of Screening Indices Calculated for Each Assessment
(Screening Indices in bold exceed the Decision Guide of 1×10^{-4})

Assessment	LEVEL I	LEVEL II
Scarboro Community from Releases from the Y-12 Complex	**1.9×10^{-3}**	8.3×10^{-5}
Union/Lawnville Community from Releases from the K-25/S-50 Complex	**2.1×10^{-4}**	3.0×10^{-5}
Jones Island Community from Releases from the X-10 Complex	7.6×10^{-5}	NA

NA = Not Assessed, as the Level I assessment is below the decision guide



Note: All values are rounded to two significant figures.

Figure 4-1: Summary of Screening Indices

The results from Table 4-6 show that both the Scarboro Level I and Level II assessments for Y-12 exceed the decision guide of 1 in 10,000. For the Union/Lawnville assessment for K-25/S-50 releases, the decision guide for the Level I assessment is exceeded. Since the screening index for the Level I X-10 assessment does not exceed the decision guide, a Level II assessment was not necessary. An analysis of these results is presented for each of the three assessments in the following sections.

4.5 Analysis of Uranium Screening Indices from Y-12 Releases

As presented in Table 4-6, the screening indices for both the Level I and Level II assessments of Y-12 releases exceeded the decision guide of 1 in 10,000. To identify the media and isotopes of importance, Table 4-7 presents the screening indices for each component of the assessment.

Table 4-7: Screening Indices for the Scarboro Community from Uranium Releases from Y-12
(Screening Indices in bold exceed the Decision Guide of 1×10^{-4})

Exposure Media		**LEVEL I**	**LEVEL II**
Air Releases from Y-12	$^{234/235}$U	**1.2×10^{-4}**	1.9×10^{-5}
	^{238}U	2.3×10^{-5}	3.1×10^{-6}
EFPC Water Concentrations	$^{234/235}$U	2.5×10^{-5}	1.4×10^{-5}
	^{238}U	2.1×10^{-5}	1.2×10^{-5}
Soil Concentrations near Scarboro	$^{234/235}$U	**9.8×10^{-4}**	2.0×10^{-5}
	^{238}U	**7.7×10^{-4}**	1.6×10^{-5}
TOTAL ACROSS ALL MEDIA	$^{234/235}$U	**1.1×10^{-3}**	5.3×10^{-5}
	^{238}U	**8.1×10^{-4}**	3.0×10^{-5}
TOTAL SCREENING INDEX FROM ALL MEDIA & ISOTOPES		**1.9×10^{-3}**	8.3×10^{-5}

For the Level I assessment, the decision guide is exceeded by the following pathway and isotope combinations:

- **$^{234/235}$U** from **air** releases from Y-12,
- **$^{234/235}$U** from **soil** concentrations at Scarboro, and
- **^{238}U** from **soil** concentrations at Scarboro.

For the Level II assessment, no one combination of isotope and media exceeded the decision guide. In addition, the total screening index from all media and isotopes was below the 1 in 10,000 decision guide. The Level I assessment represented a maximally exposed individual, due to the use of upper bound values used for both uranium concentrations in soil and exposure parameters. The Level II assessment actually represented a refined Level I screening, as discussed earlier. Soil pathways were associated with the highest screening index, followed by water pathways and then air pathways. To identify which exposure media were major contributors to the Scarboro screening index, their contributions to the total screening index is depicted in Figure 4-2.

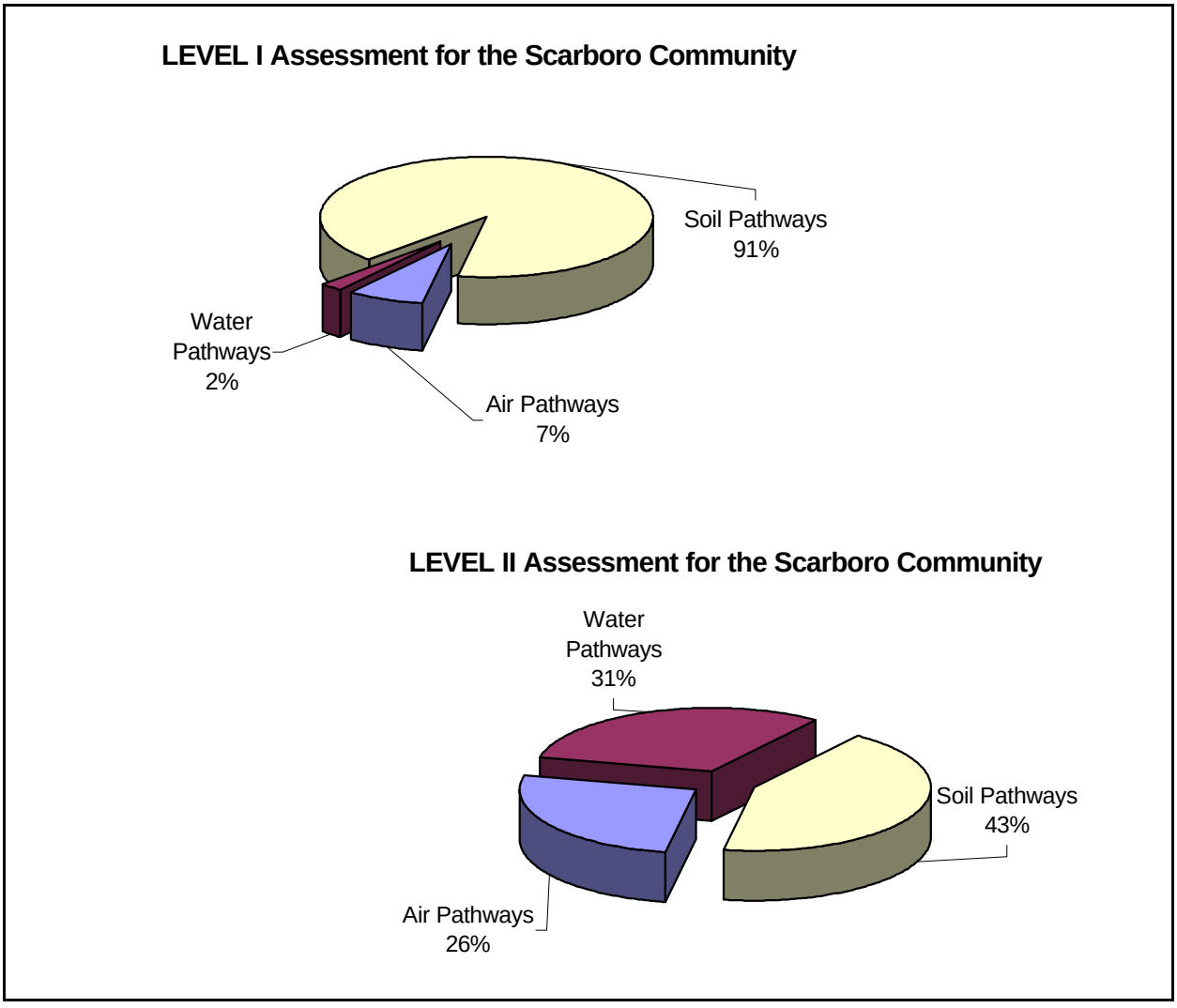


Figure 4-2: Relative Contributions to the Scarboro Screening Indices from the Exposure Media (Y-12 Releases)

Figure 4-2 presents the relative fraction for exposure from each of the three exposure media. For the Level I assessment, exposure was dominated by the soil pathways. For the Level II assessment, the contributions from the air and water pathways become more significant. The distinction between the two exposure assessments can be attributed to two factors:

(1) For the Level I assessment, the maximum concentration measured in surface soil in the vicinity of the Scarboro community was used. Due to the conservative nature of the Level I assessment, these maximum concentrations translate into significant contributions to the screening index.

(2) For the Level II assessment, an average soil concentration value for the Scarboro community was used. This fact, along with less conservative estimates of exposure parameters, limited the significance of the soil pathways, and their relative importance was reduced. The differences in exposure parameters between a Level I and a Level II assessment were most significant for the soil pathways. Consumption rates, as well as the fraction of vegetables grown in contaminated soil, were significantly reduced for a Level II assessment, and these factors also limited the significance of the soil pathways.

To identify which pathways for each exposure media contributed the most to the total screening index, Tables 4-8 through 4-13 present the doses in sieverts (Sv) for the Scarboro community from Y-12 uranium releases. Tables 4-8, 4-9, and 4-10 present the pathway components for $^{234/235}$U, and tables 4-11, 4-12, and 4-13 present doses for the ^{238}U exposures. The third and fifth columns present the percent that each pathway contributes to the total dose for that specific isotope of uranium. The doses are summed over 52 years of exposure.

For the **Level I** assessment of $^{234/235}$U, the major pathways of exposure are:

1. consumption of vegetables grown in contaminated soil,
2. consumption of milk from dairy cattle receiving pasture grown in contaminated soil,
3. external dose from $^{234/235}$U concentrations in soil,
4. the inhalation of airborne $^{234/235}$U, and
5. consumption of vegetables contaminated with deposited airborne particulates.

For the **Level II** assessment of $^{234/235}$U, the major pathways of exposure are:

1. the inhalation of airborne $^{234/235}$U,
2. consumption of vegetables grown in contaminated soil,
3. consumption of fish caught in the EFPC,
4. consumption of vegetables contaminated with deposited particulates, and
5. external dose from $^{234/235}$U concentrations in soil.

Table 4-8: Dose Estimates from $^{234/235}$U Exposure at the Scarboro Community via Air Pathways

	LEVEL I		LEVEL II	
EXPOSURE PATHWAY TO HUMANS	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total $^{234/235}$U Dose (All Pathways)	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total $^{234/235}$U Dose (All Pathways)
Inhalation of Airborne Particulates	7.7×10^{-4}	5 %	2.2×10^{-4}	30 %
Immersion in Airborne Particulates	2.5×10^{-9}	< 1%	7.6×10^{-10}	< 1%
Air to Livestock, Meat Ingestion	1.2×10^{-8}	< 1%	1.4×10^{-9}	< 1%
Air to Dairy Cows, Milk Consumption	3.0×10^{-8}	< 1%	4.3×10^{-9}	< 1%
Air to Vegetables, Consumption	7.7×10^{-4}	5 %	2.8×10^{-5}	4 %
Air to Pasture to Livestock to Beef	3.8×10^{-5}	< 1%	1.3×10^{-6}	< 1%
Air to Pasture to Dairy Cows to Milk	9.6×10^{-5}	< 1%	3.1×10^{-6}	< 1%
SUM OF DOSES FROM AIR PATHWAYS	**1.7×10^{-3}**	**11 %**	**2.5×10^{-4}**	**35 %**

Table 4-9: Dose Estimates from $^{234/235}$U Exposure at the Scarboro Community via Water Pathways

	LEVEL I		LEVEL II	
EXPOSURE PATHWAY TO HUMANS	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total $^{234/235}$U Dose (All Pathways)	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total $^{234/235}$U Dose (All Pathways)
Incidental Ingestion of EFPC Water	1.3×10^{-6}	< 1%	1.2×10^{-6}	< 1%
Water to Livestock, Meat Ingestion	4.4×10^{-5}	< 1%	4.7×10^{-6}	< 1%
Water to Dairy Cows, Milk Consumption	1.1×10^{-4}	< 1%	1.3×10^{-5}	2%
Water to Fish, Fish Consumption	1.8×10^{-4}	1%	1.8×10^{-4}	24%
Immersion in EFPC Water (recreational)	3.0×10^{-8}	< 1%	2.8×10^{-8}	< 1%
SUM OF DOSES FROM WATER PATHWAYS	**3.4×10^{-4}**	**2%**	**2.0×10^{-4}**	**27%**

Table 4-10: Dose Estimates from $^{234/235}$U Exposure at the Scarboro Community via Soil Pathways

	LEVEL I		LEVEL II	
EXPOSURE PATHWAY TO HUMANS	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total $^{234/235}$U Dose (All Pathways)	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total $^{234/235}$U Dose (All Pathways)
Inhalation of Resuspended Dust	2.6×10^{-4}	2%	1.4×10^{-5}	2%
Soil Ingestion	1.8×10^{-4}	1%	5.7×10^{-6}	< 1%
Soil to Livestock, Meat Ingestion	2.5×10^{-4}	2%	2.7×10^{-6}	< 1%
Soil to Dairy Cattle, Milk Consumption	5.2×10^{-4}	3%	6.8×10^{-6}	< 1%
Soil to Vegetables, Consumption	9.4×10^{-3}	61%	2.2×10^{-4}	30%
Soil to Pasture to Livestock, Beef Ingestion	5.0×10^{-4}	3%	3.1×10^{-6}	< 1%
Soil to Pasture to Cows, Milk Consumption	1.3×10^{-3}	8%	7.4×10^{-6}	< 1%
Soil to Humans, External Exposure	1.1×10^{-3}	7%	1.9×10^{-5}	3%
SUM ACROSS SOIL PATHWAYS	**1.4×10^{-2}**	**87%**	**2.8×10^{-4}**	**38%**

Table 4-11: Dose Estimates from ^{238}U Exposure at the Scarboro Community via Air Pathways

	LEVEL I		LEVEL II	
EXPOSURE PATHWAY TO HUMANS	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total ^{238}U Dose (All Pathways)	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total ^{238}U Dose (All Pathways)
Inhalation of Airborne Particulates	1.4×10^{-4}	1 %	4.0×10^{-5}	10 %
Immersion in Airborne Particulates	2.6×10^{-13}	< 1%	7.7×10^{-14}	< 1%
Air to Livestock, Meat Ingestion	2.3×10^{-9}	< 1%	2.7×10^{-10}	< 1%
Air to Dairy Cows, Milk Consumption	5.9×10^{-9}	< 1%	8.4×10^{-10}	< 1%
Air to Vegetables, Consumption	1.5×10^{-4}	1 %	2.1×10^{-6}	< 1%
Air to Pasture to Livestock to Beef	7.5×10^{-6}	< 1%	1.5×10^{-7}	< 1%
Air to Pasture to Dairy Cows to Milk	1.9×10^{-5}	< 1%	3.6×10^{-7}	< 1%
SUM ACROSS AIR PATHWAYS	**3.2×10^{-4}**	**3 %**	**4.3×10^{-5}**	**10 %**

Table 4-12: Dose Estimates from ^{238}U Exposure at the Scarboro Community via Water Pathways

	LEVEL I		LEVEL II	
EXPOSURE PATHWAY TO HUMANS	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total ^{238}U Dose (All Pathways)	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total ^{238}U Dose (All Pathways)
Incidental Ingestion of EFPC Water	1.1×10^{-6}	< 1%	1.0×10^{-6}	< 1%
Water to Livestock, Meat Ingestion	3.7×10^{-5}	< 1%	3.9×10^{-6}	< 1%
Water to Dairy Cows, Milk Consumption	9.2×10^{-5}	< 1%	1.1×10^{-5}	3%
Water to Fish, Fish Consumption	1.5×10^{-4}	1%	1.5×10^{-4}	35%
Immersion in EFPC Water (recreational)	1.3×10^{-11}	< 1%	1.3×10^{-11}	<1%
SUM OF DOSES FROM WATER PATHWAYS	**2.8×10^{-4}**	**3%**	**1.6×10^{-4}**	**39%**

Table 4-13: Dose Estimates from ^{238}U Exposure at the Scarboro Community via Soil Pathways

	LEVEL I		LEVEL II	
EXPOSURE PATHWAY TO HUMANS	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total ^{238}U Dose (All Pathways)	Committed Effective Dose Equivalent (Sv)	% Pathway Contributes to Total ^{238}U Dose (All Pathways)
Inhalation of Resuspended Dust	2.1×10^{-4}	2%	1.0×10^{-5}	3%
Soil Ingestion	1.6×10^{-4}	1%	4.7×10^{-6}	1%
Soil to Livestock, Meat Ingestion	2.1×10^{-4}	2%	2.3×10^{-6}	< 1%
Soil to Dairy Cattle, Milk Consumption	4.4×10^{-4}	4%	5.6×10^{-6}	1%
Soil to Vegetables, Consumption	8.0×10^{-3}	72%	1.8×10^{-4}	43%
Soil to Pasture to Livestock, Beef Ingestion	4.3×10^{-4}	4%	2.6×10^{-6}	< 1%
Soil to Pasture to Dairy Cattle, Milk Consumption	1.1×10^{-3}	10%	6.2×10^{-6}	1%
Soil to Humans, External Exposure	1.9×10^{-6}	< 1%	3.7×10^{-8}	< 1%
SUM OF DOSES FROM SOIL PATHWAYS	**1.1×10^{-2}**	**95%**	**2.1×10^{-4}**	**51%**

While many of the same pathways that were significant for Level I are also important for the Level II assessment, the relative rank of the pathways has changed. This change is due to the change in both soil concentration values used and the use of less conservative exposure parameters characterizing consumption.

For the **Level I** assessment of ^{238}U, the major pathways of exposure are:

1. consumption of vegetables grown in contaminated soil,
2. consumption of milk from dairy cattle receiving pasture grown in contaminated soil,
3. consumption of milk from dairy cattle ingesting contaminated soil,
4. consumption of meat from livestock receiving pasture grown in contaminated soil, and
5. consumption of milk from dairy cattle ingesting contaminated soil.

For the **Level II** assessment of ^{238}U, the major pathways of exposure are:

1. consumption of vegetables grown in contaminated soil,
2. consumption of fish caught in the EFPC,
3. inhalation of airborne ^{238}U,
4. consumption of milk from dairy cattle receiving water from the EFPC, and
5. the inhalation of resuspended dust contaminated with ^{238}U.

For the Level I assessment, the major pathways of exposure are from ^{238}U concentrations in soil. For the Level II assessment, the upper bound concentration in soil was replaced with an average value, which reduces the significance of these pathways. However, 43% of the dose from ^{238}U was from the ingestion of vegetables grown in contaminated soil. Plant uptake values (used to evaluate uranium concentrations in plants) are highly dependent upon the characteristics of the soil and the chemical properties of the contaminant. Site specific data would need to be collected for further refinements to this analysis. Another pathway is the consumption of fish caught in EFPC. Even though the consumption rate of fish from this source is relatively low, the concentrations in EFPC and the accumulation of uranium in fish elevate the significance of this pathway.

Screening Results When Lower Scarboro Soil Concentrations are Assumed

Additional screening calculations were performed to illustrate how the results would differ if lower levels of uranium contamination in Scarboro soil were assumed. Screening indices were calculated for soil concentrations of 7,000 and 2,000 pCi/kg total uranium. Again, lacking isotopic ratio information, Task 6 assumed the 7,000 and 2,000 values to be natural uranium. These additional screening evaluations for Scarboro give the reader an indication of how the overall results of the assessment would change if less conservative estimates of soil concentration were used.

Use of a soil value of 7,000 pCi/kg yielded a screening index of 5.8×10^{-5}. This was a 30% reduction of the screening index calculated for the Level II assessment. A 2,000 pCi/kg soil concentration produced a screening index of 5.1×10^{-5} (40% reduction). Note that, even though these alternative soil concentrations

(7,000 and 2,000 pCi/g) represent a 73% and 92% reduction in soil concentrations over the Level I value, respectively, the reduction in the screening index for Level II is not in proportion. The soil pathways represent only 38% of the total screening index from $^{234/235}U$ and 51% from ^{238}U. Since the concentrations in air and water were not changed for the alternative evaluations, a given reduction in soil concentration will not equal a corresponding reduction in the total screening index.

4.6 Analysis of Uranium Screening Indices from the K-25/S-50 Facility

An assessment of the screening indices associated with air releases from the K-25/S-50 complex was made based on air concentrations at the Union/Lawnville area. Maximum soil concentrations measured near that area were used to evaluate soil-based exposures, and the Clinch River was used as a source of fish and recreational use. Exposure durations and fish consumption rates were higher than those used for the Y-12 and combined assessments, as the Clinch River is better suited to water-based recreational activities. Table 4-14 presents the results of the K-25/S-50 assessment, presented by environmental medium and by uranium isotope.

Table 4-14: Summary of Screening Indices for the Union/Lawnville Community from Uranium Releases from K-25/S-50
(Screening Indices in bold exceed the Decision Guide of 1×10^{-4})

Exposure Media		**LEVEL I**	**LEVEL II**
Air Releases from K-25/S-50	$^{234/235}U$	4.3×10^{-5}	6.5×10^{-6}
	^{238}U	1.8×10^{-5}	2.5×10^{-6}
Clinch River Water Concentrations	$^{234/235}U$	2.0×10^{-6}	1.5×10^{-6}
	^{238}U	1.7×10^{-6}	1.3×10^{-6}
Soil Concentrations near Union/Lawnville	$^{234/235}U$	**1.0×10^{-4}**	1.4×10^{-5}
	^{238}U	4.4×10^{-5}	5.0×10^{-6}
TOTAL ACROSS ALL MEDIA	$^{234/235}U$	**1.5×10^{-4}**	2.2×10^{-5}
	^{238}U	6.4×10^{-5}	8.7×10^{-6}
TOTAL SCREENING INDEX FROM ALL MEDIA & ISOTOPES		**2.1×10^{-4}**	3.0×10^{-5}

As shown by the screening indices presented in Table 4-14, results of the Level I assessment for the Union/Lawnville area from K-25/S-50 releases exceeds the decision guide of 1 in 10,000 (1×10^{-4}). The only media/isotope combination that exceeds the guide is $^{234/235}U$ exposure from soil concentrations. Air releases from K-25/S-50 are significantly lower than those from Y-12; hence the relative contribution to the total screening index from air pathways is less significant than those estimated for the Scarboro assessment . However, as shown in Figure 4-3, the air pathway still accounts for 23% of the screening index at Union/Lawnville.

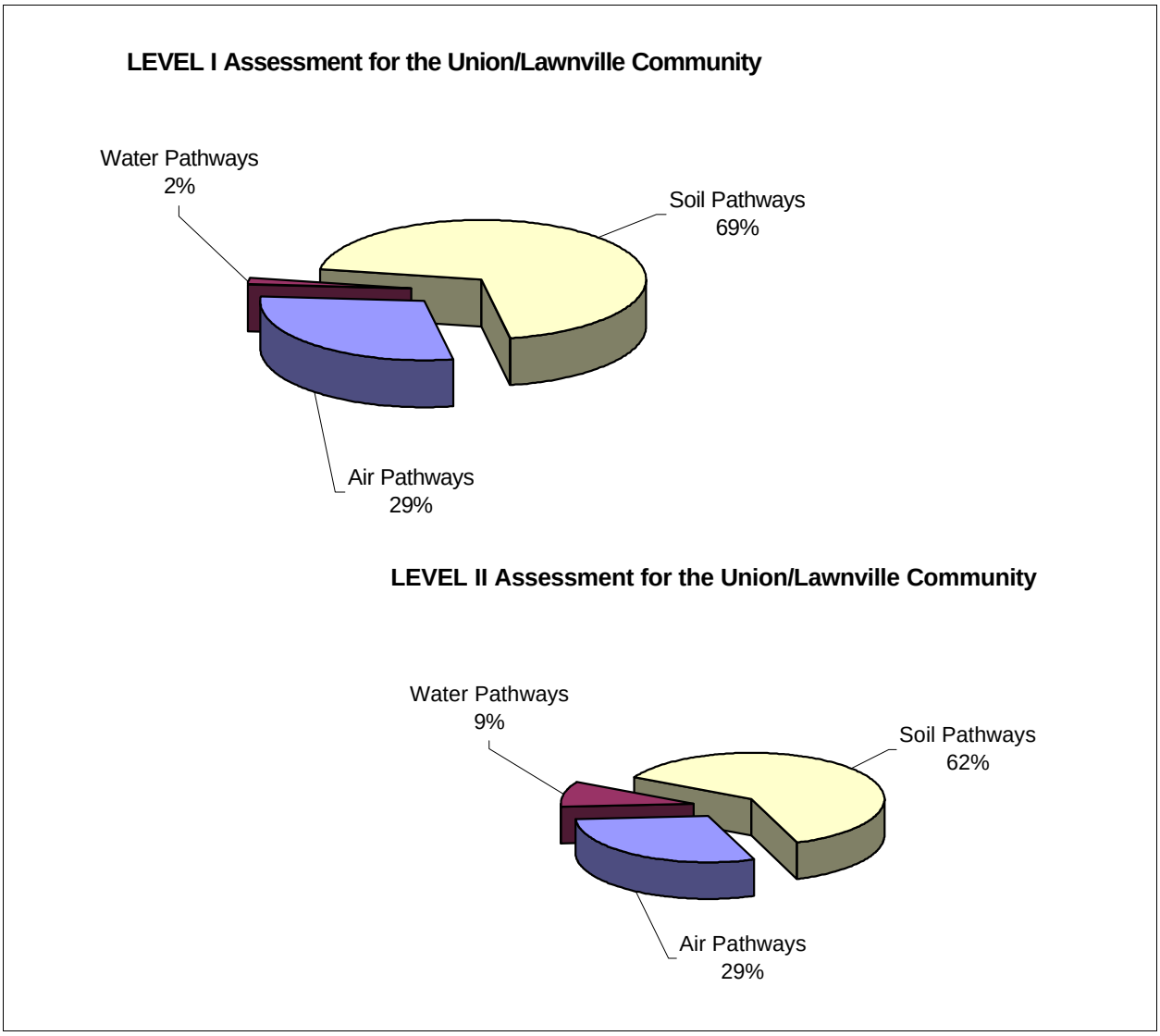


Figure 4-3: Relative Contributions to Union/Lawnville Screening Indices from the Key Exposure Media (K-25/S-50 Releases)

As limited soil concentration data were available, the same exposure concentration was used for both Level I and Level II assessments. Soil data were usually collected in response to environmental compliance needs of the operational facility. Soil samples were rarely collected from populated areas. Given the constraints of the Task 6 work, additional investigation into other possible sources of soil measurements was not possible. Should this analysis proceed to the dose reconstruction level, further search, for and analysis of, the available environmental monitoring data could be conducted.

4.7 Analysis of Uranium Screening Indices from the X-10 Facility

The predominant direction of atmospheric transport off-site from the X-10 facility is toward the southwest. The reference location for X-10 releases was on the banks of the Clinch River near the northern end of Jones Island. This area is approximately 5 km southwest of the site. Soil concentrations from the vicinity of the X-10 site were used to evaluate potential exposures via soil-based pathways. Due to its proximity, the Clinch River was considered an area for water-based recreational exposure and a source of fish. As was the case for the K-25/S-50 assessment, exposure durations and fish consumption rates were higher than those assumed for the Y-12 and combined assessments, as the Clinch River was better suited to water-based recreational activities than was EFPC. The screening indices calculated for Jones Island from X-10 releases are presented in Table 4-15.

Table 4-15: Summary of Screening Indices for the Jones Island Community from Uranium Releases from X-10

Exposure Media		**LEVEL I**
Air Releases from X-10 (1944-1957)	$^{234/235}U$	6.7×10^{-9}
	^{238}U	1.6×10^{-7}
Clinch River Water Concentrations	$^{234/235}U$	2.0×10^{-6}
	^{238}U	1.7×10^{-6}
Soil Concentrations near Jones Island	$^{234/235}U$	5.3×10^{-5}
	^{238}U	2.0×10^{-5}
TOTAL FROM ALL MEDIA	$^{234/235}U$	5.5×10^{-5}
	^{238}U	2.2×10^{-5}
TOTAL SCREENING INDEX FROM ALL MEDIA & ISOTOPES		**7.6×10^{-5}**

.

Since the decision guide was not exceeded in the Level I assessment, a Level II assessment was not performed. The exposure durations used for the Jones Island assessment differ from those used for the other assessments. The uranium air releases from X-10 were primarily during the period 1944 to 1957. The release quantities were minor compared to releases from the Y-12 and K-25/S-50 complexes, hence the significance of the air releases was limited. Soil and water exposure durations were for the duration of facility operation (52 years). As it not possible to retrospectively ascertain the concentration of uranium in soils with respect to time, the selected soil concentration was also assumed to be constant for the 52 years of exposure.

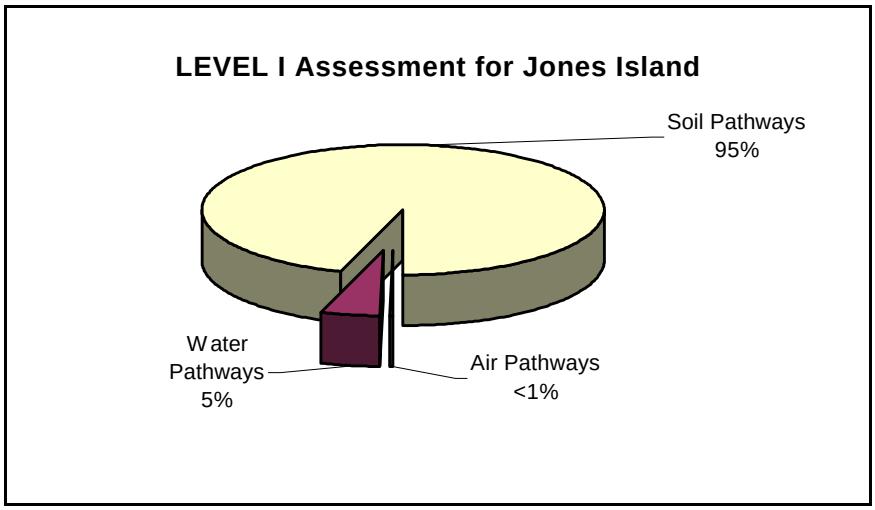


Figure 4-4: Relative Contributions to the Jones Island Screening Indices from the Exposure Media (X-10 Releases)

4.8 Effect of K-25/S-50 Air Releases at Scarboro

Air concentrations at the Scarboro community from K-25/S-50 air releases were determined using the ISCST3 approach used for Union/Lawnville concentrations from K-25/S-50. Annual average air concentrations at Scarboro from K-25/S-50 releases were 0.2 fCi m^{-3} for $^{234/235}U$, and 0.09 fCi m^{-3} for ^{238}U. Adding these concentrations to the air concentrations due to Y-12 releases of 14.4 fCi m^{-3} for $^{234/235}U$ and 3.1 fCi m^{-3} for ^{238}U, results in a 1% increase in $^{234/235}U$ air concentrations and a 3% increase in ^{238}U air concentrations from Y-12 alone. The air concentrations from K-25/S-50 result in a less than 0.1% increase in the screening index for the Scarboro community from Y-12 alone. Thus, the effect of K-25/S-50 air releases at Scarboro is relatively small.

4.9 Uranium Chemical Toxicity Evaluation

This section discusses the methodology and results of the chemical toxicity evaluation for uranium exposures, and summarizes ways that this assessment could be refined if future iterations of the Task 6 analysis are conducted. A screening assessment of possible toxic effects from ingestion and inhalation of uranium by residents of Scarboro was performed by the project team. The Scarboro community was selected for this initial chemical toxicity evaluation since the screening index for radiological exposures was the highest among all three assessments. The chemical toxicity evaluation could be performed for the other screening assessments if a further study of ORR uranium releases is undertaken. Using annual average rates of uranium ingestion and inhalation estimated by Task 6, and biokinetic models of human physiology for uranium retention and excretion in the body, kidney doses (burdens) over time were calculated. Predicted uranium burdens were compared to toxicity thresholds reported in the scientific literature. For conservative screening purposes, uranium intakes were assumed to be in the most soluble form, and safety factors were included to minimize the potential for underestimating toxic effects in this screening assessment.

4.9.1 Chemical Effects Threshold Criterion

Uranium toxicity can occur in a variety of tissues including the kidney, lung and bone, depending on the dose, route of exposure and chemical form. However, the kidney is considered to be the critical target organ for the chemical effects of absorbed uranium. The effects threshold criterion used in this assessment, 0.02 microgram of uranium per gram of kidney tissue, is based on application of a safety factor of 50 to the toxic threshold for uranium in the kidney of 1 $\mu g\ g^{-1}$. A detailed literature review supporting these values is described in Appendix M.

4.9.2 Task 6 Conceptual Approach

The objective of this assessment was to estimate the highest uranium concentration in kidney during each year of chronic inhalation and ingestion exposures and compare the total concentration to the protection criterion. Uranium intakes were based upon measured or predicted total uranium concentrations in air, water, and soil at the reference location that exhibited the highest radiological screening index (Scarboro community).

Throughout each year of exposure, daily intake rates by ingestion and inhalation were assumed to be constant. Biokinetic models of the lung, GI tract, circulatory system, bone and kidneys recommended by the International Commission on Radiological Protection (ICRP) and implemented in the LUDEP 2.0 model (NRPB 1995) were used to calculate the uranium concentration in the kidney for each annual intake. Uranium concentrations in kidney from ingestion and inhalation were modeled separately, and the predicted uranium concentrations in kidney were summed for comparison to the protection criterion. The kidney model has two compartments, with retention half-times of 7 and 1500 days. Consequently, the uranium concentration in one compartment of the kidney responds quickly (within a few days) to changes in intake. The other compartment fills or empties slowly (over a period of years) when intakes of uranium are increased or decreased, respectively. Details regarding uranium retention and excretion can be found in Appendix M.

4.9.3 Ingestion

The concentration of uranium in kidney tissue during and after the ingestion of uranium at a constant rate of 1 $\mu g\ d^{-1}$ for one year was calculated using LUDEP 2.0 developed by the National Radiological Protection Board (NRPB 1995). The model uses ICRP Publication 30 biokinetic models and parameter values to represent the GI tract, circulatory system, skeleton and kidneys. The chemical form of the ingested uranium was assumed to have the highest bioavailability, therefore, the factor used to calculate transfer from the GI tract to the circulatory system was set at the higher of the two recommended values (0.05).

The cumulative concentration of uranium in kidney tissue from combined effects of ingestion via all complete exposure pathways for the period 1944 to 1990 was computed by making separate calculations for each year of intake ($\mu g\ d^{-1}$) and summing the predicted concentrations in each year. The annual intake rates were multiplied by the modeled unit concentrations to arrive at the predicted uranium kidney burdens ($\mu g\ g^{-1}$) for the period 1944 to 1990. The results of this evaluation are shown in Figure 4-5. The results do

not exceed the effects threshold criterion of 1 μg g^{-1}. However, if a criterion with a safety factor of 50 applied (0.02) is compared to the predicted kidney burdens, it indicates that possible health concerns may exist, and refinement to this assessment may be warranted. This safety factor is based in part on the new ICRP biokinetic models for the circulatory system, skeleton, and kidneys that predict almost a factor of 2 higher kidney burdens from a given intake. Discussions among scientists regarding the use of various uranium behavior models and the interpretation of various data sets continue as of today.

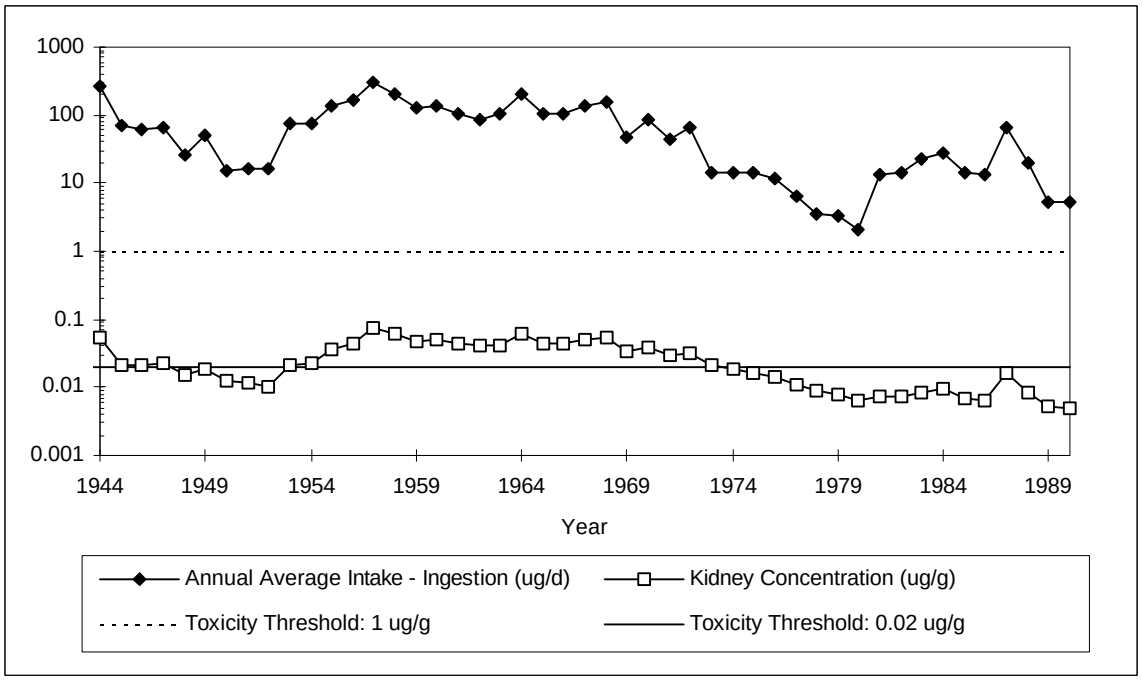


Figure 4-5: Uranium Kidney Burden (mg g^{-1}) and Annual Average Intake via Ingestion (based on ICRP Publication 30 Methods)

4.9.4 Inhalation

The concentration of uranium in kidney tissue during and after the inhalation of uranium at a constant rate of 1 μg d^{-1} for one year was also calculated using LUDEP 2.0 (NRPB 1996). The model uses the ICRP Publication 66 lung model and ICRP Publication 30 biokinetic models and parameter values to represent the GI tract, circulatory system, skeleton and kidneys. The particle size was set at 1 μm to ensure that deposition in alveolar regions of the lung was not underestimated. The chemical form of the inhaled uranium was assumed to be characterized as type F, the form which has the highest rate of transfer to the circulatory system.

The cumulative concentration of uranium in kidney tissue from inhalation throughout the years of interest was computed by using a method similar to that described above for ingestion. The results are shown in Figure 4-6.

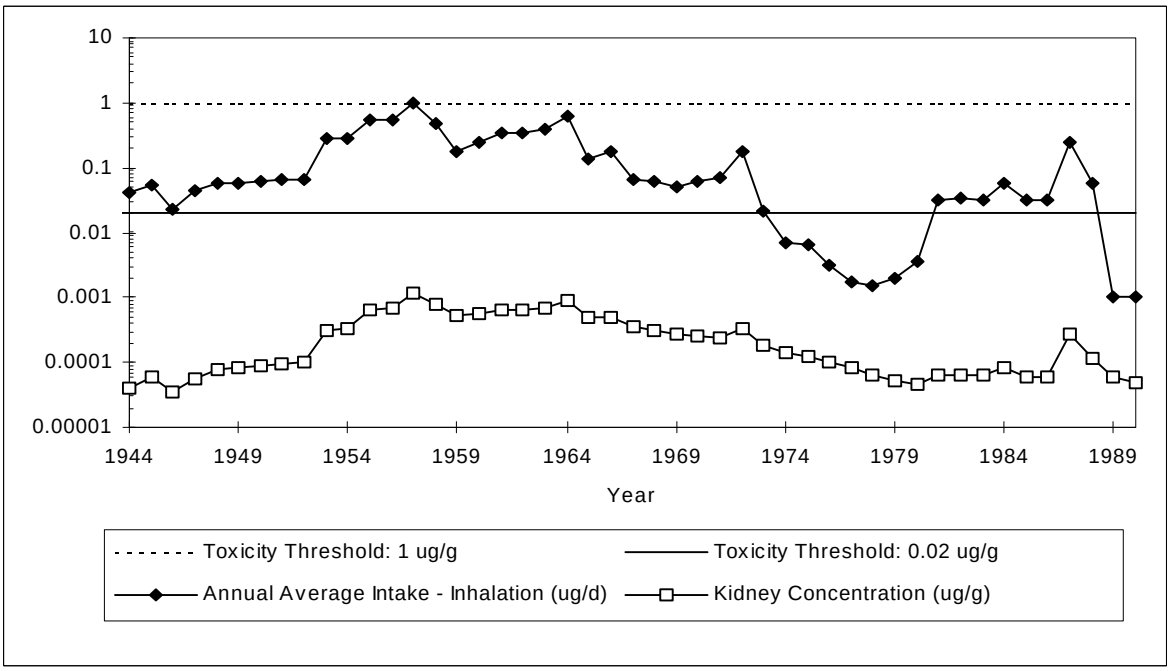


Figure 4-6: Uranium Kidney Burden (mg g^{-1}) and Annual Average Intake via Inhalation
(Based on ICRP Publication 30 Methods)

Comparing Figures 4-5 and 4-6, it is evident that the predicted kidney burdens associated with uranium inhalation are much lower than those from ingestion. Results for combined exposures (ingestion and inhalation) are shown in Figure 4-7.

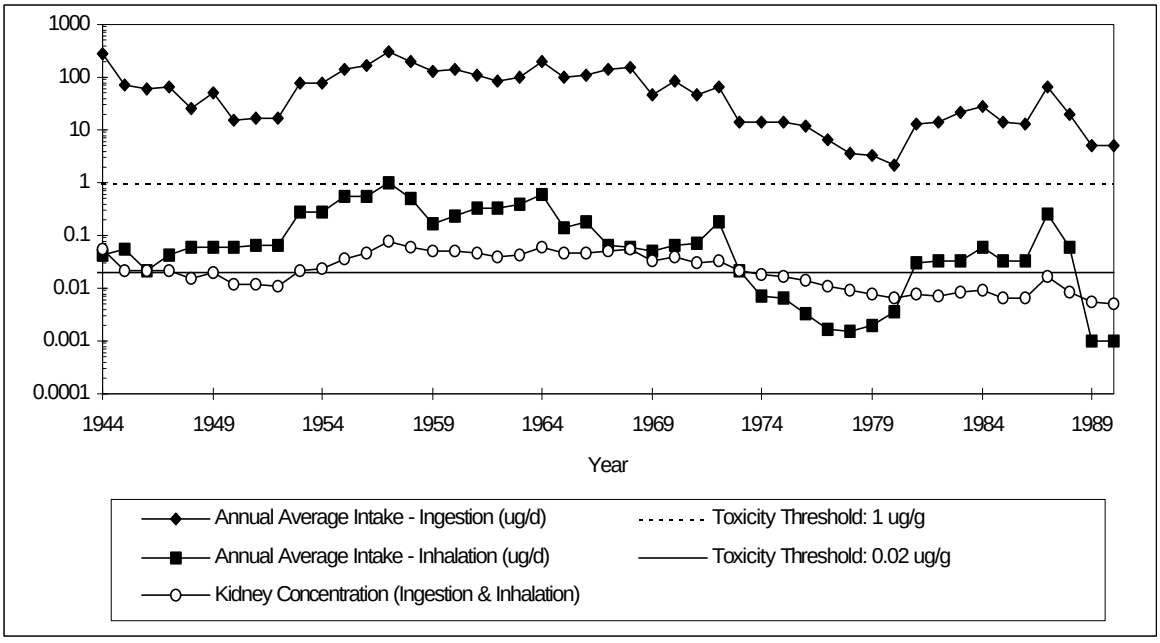


Figure 4-7: Total Uranium Burden in Kidney (mg g^{-1}) from Ingestion and Inhalation
(Based on ICRP Publication 30 Methods)

4.9.5 Discussion

The models used to estimate uranium concentrations in kidney tissue from inhalation and ingestion are recommended by the ICRP. The biokinetic models and parameter values representing the GI tract, circulatory system, skeleton and kidneys are from ICRP Publication 30 and have been adopted by both the EPA and NRC as the partial basis for the radiation dose factors.

ICRP has recently updated the lung model (in ICRP Publication 66) based on information that has been published since the ICRP 30 lung model was developed. EPA and NRC have adopted most of the ICRP recommendations in the past, and there is reason to believe that they will also adopt the ICRP 66 lung model in the future.

ICRP recently (1995) revised the biokinetic models for the circulatory system, skeleton and kidneys. Using this model, predicted uranium concentrations in kidney at steady-state (i.e. following several decades of exposure) are approximately twice the corresponding uranium concentrations in kidney predicted by the ICRP 30 models. For purposes of this assessment, it was concluded that the safety factor of 50 incorporated into the toxicity criterion provides sufficient protection to cover model uncertainty. However, it has been pointed out by other researchers that the ICRP models for predicting uranium kidney burdens are highly conservative, and can overestimate potential kidney exposure by more than an order of magnitude (Morris and Meinhold 1995). Conclusions regarding predicted kidney burdens are made difficult given the wide spectrum of opinions found in the scientific community regarding the biokinetics and chemical toxicity of uranium.

If intakes were found to be quite variable throughout a given year, a more detailed temporal analysis, using shorter (even daily) time intervals would improve the accuracy of the evaluation. A formal uncertainty analysis was beyond the scope of this screening evaluation, but may be among the logical next steps if additional iterations of the Task 6 assessment are to be conducted.

4.9.6 Hazard Index

Estimates of annual-average intakes of uranium were also compared to the USEPA Oral Reference Dose (RfD) for the purpose of performing an alternative evaluation of estimating the potential impact from ORR uranium exposures. The RfD of 3×10^{-3} mg/kg d^{-1} is primarily based on animal studies and is conservatively set at a level to ensure that no observable effects are seen in the kidneys or renal function for those individuals exposed to uranium. Using estimated annual-average daily uranium intake rates via inhalation and ingestion at the Scarboro community, the project team determined annual Hazard Indices (HI) by dividing the annual-average daily intake rates by the RfD. Hazard Indices are presented in Figure ES-3. The average HI is well below unity and suggests that further study of metal toxicity effects from past ORR uranium exposures would receive low priority.

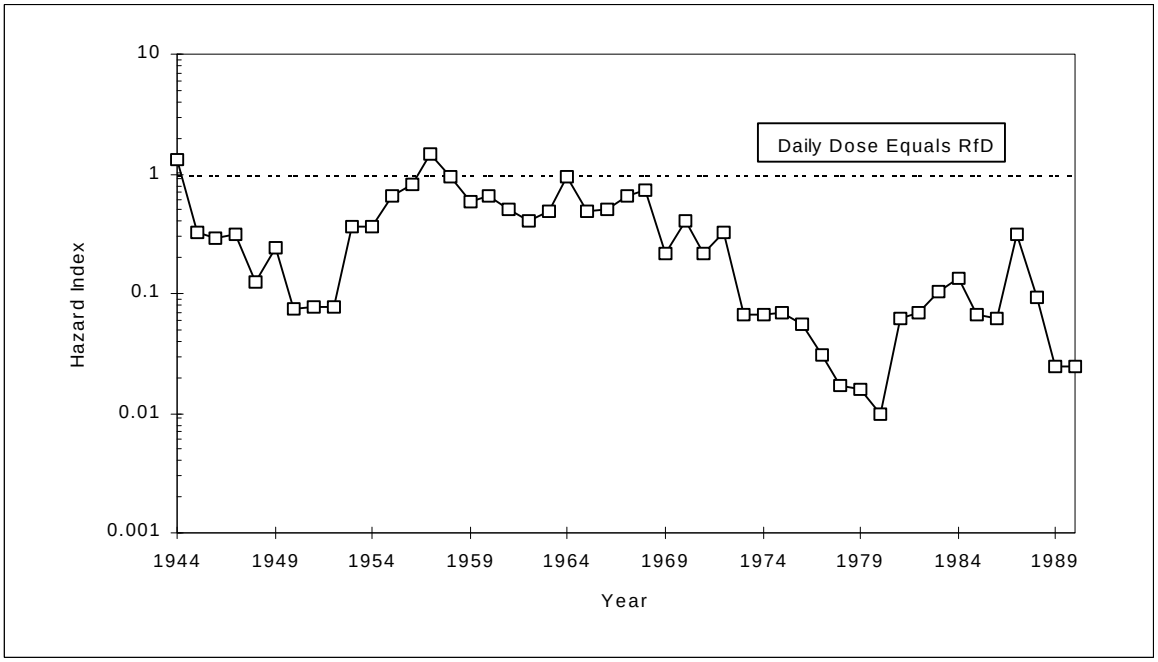


Figure 4-8: Annual Average Hazard Index for a 70 kg Person and an Oral RfD of 3×10^{-3} mg kg^{-1} d^{-1}

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5.0 CONCLUSIONS OF THE TASK 6 ASSESSMENT

The following general conclusions can be made based on the experience of the project team in conducting the Task 6 evaluation and based on the results presented in this report:

- Estimates of uranium releases from the Oak Ridge complexes that have been previously reported by the DOE and its contractors are incomplete, and should not be used as the basis for an evaluation of the potential for off-site health effects.

- Historical airborne releases of uranium from the Y-12 Plant were likely significantly higher than previously reported. As shown in Section 2, the project team's independent evaluation of past Y-12 airborne uranium releases yielded results that are over seven times higher than release totals reported by the DOE, with almost 44,000 kilograms more total uranium released than officially reported.

- There are several reasons why previous estimates were significantly lower. First, effluents from some Y-12 operations were not monitored, and estimates for these operations were in some cases not included in reported release totals. Second, some official release estimates were based on uranium accountability records, which were incomplete – especially for the less-valuable materials such as depleted uranium. And third, the personnel that derived the previous estimates for release sources that were monitored did not have a complete set of associated data assembled for their use.

- Historical airborne releases of uranium from the K-25/S-50 complex were likely higher than previously reported. As shown in Section 2, the project team's independent evaluation of past K-25/S-50 airborne uranium releases yielded results that were almost 6,000 kilograms more total uranium released than officially reported by the DOE.

- Operations at the S-50 liquid thermal diffusion plant are poorly documented in available records. The assessment of releases from this ill-fated operation would benefit from additional targeted document searching for operational records and information relevant to release mechanisms and pathways to the air, water, and soil.

- The Scarboro community was associated with the highest total screening index from uranium releases from the Y-12 facility. The estimated screening indices were 1.9×10^{-3} for the Level I assessment and 8.3×10^{-5} for the Level II assessment. These values translate into potential health impacts of 2 in 1,000 and 8 in 100,000, respectively. The Level I exposure assessment exceed the ORHASP decision guide of 1 in 10,000. Since the Level II assessment is just below the criterion with most of the conservative assumptions removed regarding source term and exposure parameters, potential exposures to uranium releases could have been of significance from a health standpoint, and should be considered for dose reconstruction.

- For the K-25/S-50 assessment, the total screening index for the community of Union/Lawnville (3 in 10, 000) exceed the decision guide for the Level I assessment. The result of the less conservative Level II assessment does not exceed the guide, however, the screening index is still of concern. Without quantification of the uncertainties associated with the release estimates and the exposure assessment, it is not possible to say that these releases do not warrant further characterization.

- The total screening index for releases from X-10 does not exceed the decision guide for Level I screening.

- The presence of Pine Ridge between the Y-12 complex and the reference location at Scarboro led the Task 6 team to alternative approaches for evaluation of uranium air concentrations. The inadequacies of simple air dispersion models became evident once predicted air concentrations were compared to concentrations reported by air monitoring stations. An empirical χ/Q approach was devised for this analysis, which was based on measured uranium air concentrations at the Scarboro monitoring station and Y-12 plant release estimates. Limitations of this approach include the fact that only 10 years of monitoring data were available from Scarboro, and these reported values were for the period 1986-1995, during which time the releases from Y-12 were considerably lower than in earlier years.

- Major factors in the screening analysis for all three assessments are the concentrations of uranium in soil. All three isotopes of uranium present a significant hazard once ingested, and with the inclusion of terrestrial pathways, such a consumption of vegetation grown in contaminated soil, concentrations of uranium in soil contribute significantly to the total screening index. With limited soil data available for the reference locations, alternative approaches such as use of additional monitoring data, air deposition models, or area weighted averages should be considered for future analysis.

- With regard to the chemical toxicity of uranium, estimated kidney burdens resulting from simultaneous intake of uranium by ingestion and inhalation under the combined assessment do not exceed an effects threshold criterion of 1 microgram of uranium per gram of kidney tissue (1 Fg g^{-1}) proposed by some scientists, but do exceed an effects threshold criterion of 0.02 Fg g^{-1} advocated by others who have studied uranium effects in the kidney. Additionally, calculated hazard indices indicate that further study of chemical effects of the kidneys would rank as a low priority.

Based upon the experience of the project team in conducting the Dose Reconstruction Feasibility Study and the Task 6 evaluation, a number of areas have been identified that are logical next steps in the evaluation of potential health effects from Oak Ridge uranium releases. These areas, which are identified

throughout this report, involve components of the study that the project team believes are significant contributors to the overall uncertainty of the results of the Task 6 screening evaluation. These areas should be examined if the evaluation of Oak Ridge uranium releases is to proceed beyond the conservative screening stage, and on to nonconservative screening and possibly a stage of refined evaluations that would likely include uncertainty and sensitivity analyses to assist in the decision making process. Activities that should be evaluated for possible follow up work include:

(1) Additional records research and data evaluation regarding S-50 Plant operations and potential releases.

(2) Additional searching for and review of effluent monitoring data for Y-12 electromagnetic enrichment operations from 1944 to 1947 and data relating to (unmonitored) depleted uranium operations in the 1950s through 1990s.

(3) Uncertainty analysis of the Y-12 uranium release estimates derived in this study.

(4) Review of additional data regarding unmonitored K-25 uranium releases.

(5) Refinement of the approach used to evaluate surface water and soil-based exposure concentrations. This refined analysis could possibly involve shifting to a source term-based approach and use of additional environmental measurement data.

(7) Improved atmospheric air modeling for K-25/S-50 and X-10 by using wind data from multiple stations and years. This work could include evaluation of the effects of the ridges and valleys that dominate the local terrain surrounding Y-12 and Scarboro and investigation of alternative approaches to estimate air concentrations at Scarboro with an emphasis on using additional monitoring data. Evaluation of the uncertainty associated with air concentrations would provide upper and lower bounds of confidence in the estimates.

(8) Performance of a bounding assessment of the amounts of uranium that were handled at the X-10 site, for comparison with Y-12 and K-25/S-50, and for evaluation of the feasibility of generating a more complete air source term for uranium.

(9) Improvement of the exposure assessment to include region-specific consumption habits and lifestyles, identification of likely exposure scenarios instead of hypothetical upper bound and typical assessments, and inclusion of uncertainty analysis to provide statistical bounds for the evaluations of risk.

(10) Refinement of the chemical toxicity evaluation, possibly to include other approaches/models and an uncertainty analysis.

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APPENDIX A

DESCRIPTIONS OF KEY URANIUM OPERATIONS AT Y-12

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This appendix contains descriptions of historical Y-12 uranium process operations and locations and mechanisms within those operations that released uranium to the off-site environment. Through a series of maps that highlight specific buildings and their functions, and tables that discuss further the role of each building or process, the reader can develop an understanding of Y-12 uranium operations and key release sources. These maps show buildings with similar missions grouped by degrees of shading. Y-12 experienced significant changes from their original mission (electromagnetic enrichment; 1944-1947), and eventually became a large producer of highly-enriched uranium weapon components. Tables and figures contained in this appendix depict the changes in Y-12 operations that occurred over time and identify the key uranium release sources. Table A-1 provides an overall chronology of historical operations by building.

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Table A-1: Chronology of Y-12 Uranium Process Buildings

Building	1943-1948	1949-1951	1952-1963	1964-1995
9201-1	Tracks 1 and 2, á - I calutrons (uranium enrichment)	Uranium enrichment operations	Uranium salvage operations	Fusion energy research operations
9201-2	Tracks 3 and 4, á - I calutrons (uranium enrichment)	Uranium enrichment operations	COLEX Lithium/Hg enrichment operations	Development/research operations
9201-3	Track 5, á - I calutrons	Uranium enrichment operations	Uranium salvage operations	Fusion energy research operations
9201-4	Tracks 6 and 7, á - II calutrons (uranium enrichment)	Uranium enrichment operations	COLEX Lithium/Hg enrichment operations	Engineering/administrative facilities
9201-5	Tracks 8 and 9, á - II calutrons (uranium enrichment)	Uranium enrichment operations	COLEX Lithium/Hg enrichment operations	Normal/depleted uranium press, rolling, and machining operations
9202	á and & chemical preparation/recovery operations	Uranium product recovery operations	Uranium process development & improvement operations	Uranium process development & improvement operations
9203	^{235}U analysis and initial uranium product processing	Uranium product recovery operations	Recovery and salvage operations	Y-12 production development and research operations
9204-1	Tracks 1 and 2, ß - calutrons (uranium enrichment)	Uranium enrichment operations	Stable isotope separation operations	Fusion energy research operations
9204-2	Tracks 3 and 4, ß calutrons (uranium enrichment)	Uranium enrichment operations	Uranium assembly operations	Uranium assembly operations
9204-3	Tracks 5 and 6, ß calutrons (uranium enrichment)	Uranium enrichment operations	Stable isotope (*e.g.*, copper) separation operations	Stable isotope (*e.g.*, copper) separation operations
9204-4	Tracks 7 and 8, ß calutrons (uranium enrichment)	Uranium enrichment operations	ELEX Lithium/Hg pilot-scale operations	Normal/depleted uranium press and rolling operations
9206	ß chemical recycle and product processing	Uranium product recovery/salvage	Uranium chemical processing and metal production operations	Uranium chemical processing and metal production operations
9207	Uranium salvage operations	Uranium recovery/salvage	Maintenance/salvage operations	ORNL biological research operations
9211	Uranium salvage operations	Uranium salvage and product recovery operations	Uranium salvage and product recovery operations	ORNL biological research operations
9212	ß product processing	Uranium conversion/recovery operations	UF_6 conversion, chemical operations, and weapon production operations	Chemical operations and weapons production operations
9215	--	--	Enriched uranium machining and metal finishing operations	Enriched uranium machining and metal finishing operations
9998	--	Normal uranium H-1 foundry operations	Depleted uranium H-1 foundry operations	Depleted uranium H-1 foundry operations

KEY URANIUM OPERATION: Electromagnetic Enrichment

See FIGURE A-1

Brief Description of Operations, Forms of Uranium Handled:
Over the course of one year starting in 1943, Y-12 put into operation eight of nine electromagnetic enrichment process buildings, including five first-stage enrichment operations called **alpha** buildings and three second-stage enrichment operations called **beta** buildings. A fourth beta building was operating by November, 1945. As part of the war effort to build an atomic bomb, Y-12 processed roughly 50,000 kilograms of uranium tetrachloride (UCl_4), known as feed or "charge" material, in large mass spectrometers called **calutrons** that were housed in both alpha and beta enrichment buildings. Calutrons were arranged in large groups called "racetracks", typically 96 calutrons per alpha track and 36 calutrons per beta track. Each building typically housed two tracks. To obtain a desired enrichment, UCl_4 was processed through many calutrons and recycled frequently. Alpha operations enriched uranium up to 20-30% U-235. Beta operations were designed to further enrich partially-enriched, alpha recycle material up to 95% U-235. Enriched uranium compounds were recovered and converted to oxide for shipment to Los Alamos or recycled for further alpha or beta enrichment. Depleted uranium was removed from process equipment and disposed of through building vents and storm sewer drains.

Dates of Operation: 1943 - 1947

Buildings Involved: Alpha buildings 9201-1,2,3,4,and 5; Beta buildings 9204-1,2,3,and 4.

Mechanisms for Release of Uranium to the Air:

1. Initial alpha recovery operations in 9201-1 led to releases through process/building vents.
2. Incidental leaks from calutron units led to release through general building vents.

Associated release points included roof vents and stacks.

Mechanisms for Release of Uranium to Surface Waters:

1. Surface runoff from areas contaminated from process leaks to building drains and EFPC.
2. Initial alpha recovery operations in 9201-1 led to releases through drains to EFPC.

Associated release points included specific floor/sink drains which fed to the main storm sewer outfall for each building. Each outfall released water/solutions to East Fork Poplar Creek.

Effluent Treatment Provided:

1. Collection trays used to gather spilled product material. Trays were typically not used for solutions that contained depleted uranium.
2. None have been identified for controlling releases through process/building ventilation.

Physical/Chemical Forms of Uranium in Effluents: UO_3 and UCl_4

Monitoring/Sampling Data Availability: Monitoring data for early operations was generated from periodic air sampling of process operations and reported in Medical and Chemical division reports. Indoor air sampling data/uranium loss estimates are available for 1944 to 1949.

Release Estimates Available? Tennessee Eastman reports that describe uranium losses have been identified from an index listing located at the Y-12 Central Files vault. However, these reports were found to be missing from Central Files. Historical reports provide estimates of annual uranium losses from alpha and beta operation buildings (Smith et al. 1945; Griffith 1957; Owings 1986).

Accidental Releases Documented? Numerous accidental releases reportedly occurred during the war effort, involving process solutions that contain mostly depleted uranium (U-238). Documents that describe amounts released per accident were not available to the project team. Accidental releases were combined with reported releases (Griffith 1957).

Information Relevant to Estimating Releases:

1. Indoor air monitoring results for 1945 and 1946 and flowrates for general ventilation.
2. 1943 and 1947 accountability records for beta product losses to the air and EFPC.
3. Tennessee Eastman reports for 1948 through 1952 were identified from a bibliography listing, but were not located during the Task 6 investigation. If found, the Tennessee Eastman reports may be useful for future evaluations in a dose reconstruction study.

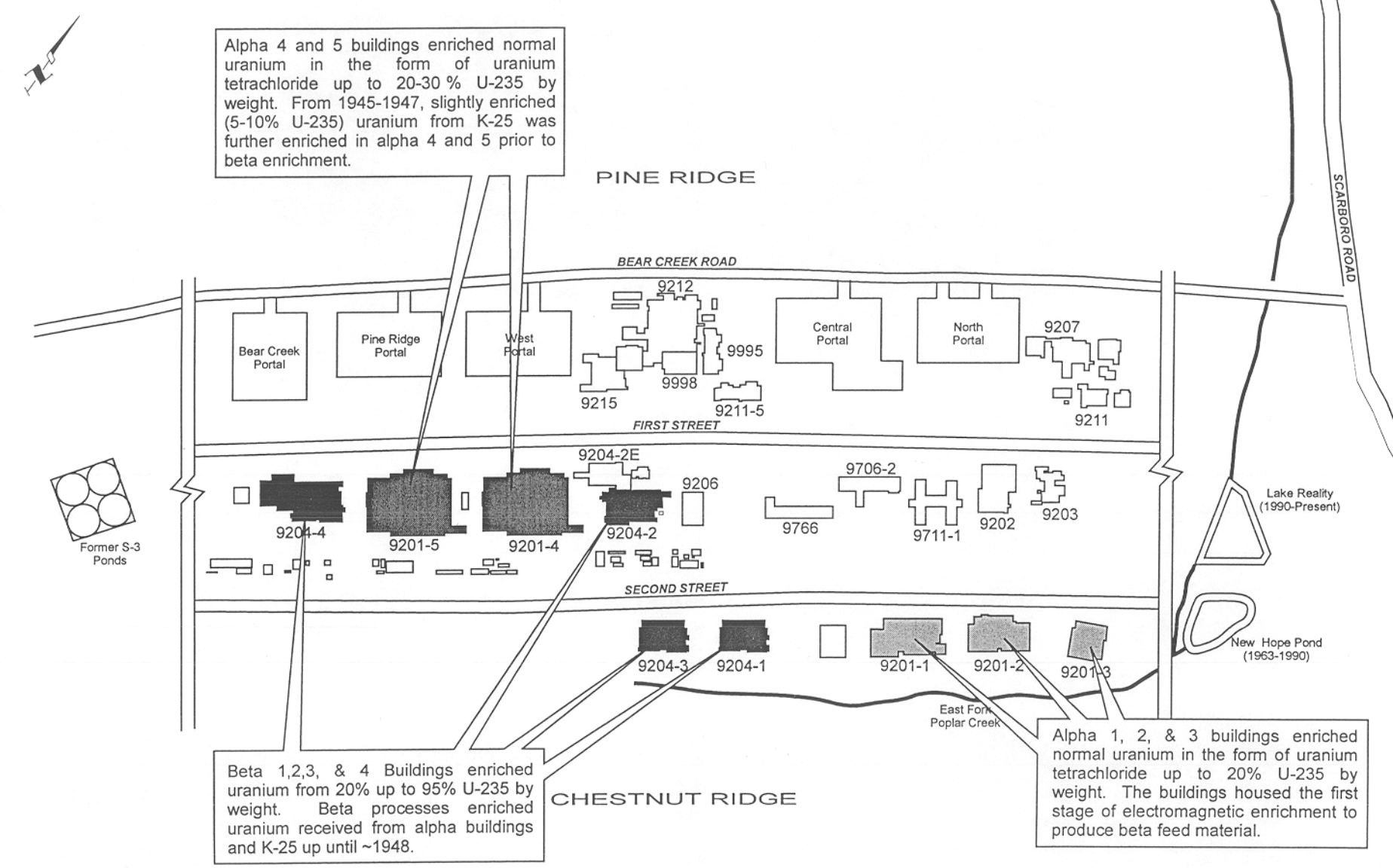

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FIGURE A-1

ELECTROMAGNETIC ENRICHMENT FACILITIES

(1943 - 1947)

KEY URANIUM OPERATION: Feed Preparation & Product Processing

See FIGURE A-2

Brief Description of Operations, Forms of Uranium Handled:
Volatile uranium tetrachloride (UCl_4), also known as "charge" material, was the chemical form of uranium fed to alpha and beta electromagnetic enrichment operations. UCl_4 was produced at Y-12 using one of two chemical conversions involving uranium trioxide (UO_3) and carbon tetrachloride. The first method was liquid-phase chlorination in which uranium and carbon tetrachloride were heated under pressure. The UCl_4 crystals formed were collected and placed in charge bottles which were then loaded into calutrons for uranium enrichment. A second method was vapor-phase chlorination in which carbon tetrachloride was gradually added to uranium trioxide under heated conditions inside a chemical reactor bowl for roughly eight hours and then purged with nitrogen to exhaust phosgene vapors from the system. From both methods, UCl_4 crystals were collected and loaded into calutrons.

The electromagnetic enrichment process was only seven or eight percent efficient, which meant that most of the uranium product or unseparated feed had to be recovered and converted back into charge material for further enrichment. After each production run, uranium compounds mostly in the form of UO_2 or $UO_2(NO_3)_2$ were recovered and either converted to UO_3 for shipment or UCl_4 for further enrichment. During the 1940s, the largest uranium releases occurred during alpha feed conversion operations. The majority of uranium was released through exhaust stacks and vents and storm sewer drains. Beta operations were controlled more closely, thus minimizing the potential for significant releases. Operations handled enriched, normal, and depleted uranium.

Dates of Operation: 1943 - 1947

Buildings Involved: 9202, 9203, 9206, and 9212.

Mechanisms for Release of Uranium to the Air:

1. Chlorination, hydrofluorination processes released U to stacks/vents (periodic monitoring).
2. Particulates and fumes from muffle furnaces released to scrubbers and filtered stacks.
3. Ash leaching process exhaust systems (periodically monitored).

Associated release points include roof vents and stacks.

Mechanisms for Release of Uranium to Surface Waters:

1. Releases of acid washes and precipitates to sewer drains and EFPC
2. Surface runoff from contaminated areas to storm sewer drains

Associated release points included numerous drains per building that fed to main outfalls and EFPC.

Effluent Treatment Provided:

1. Scrubbers on calcination and chlorination exhaust vents and stacks
2. Glass wool, cotton filters, rotoclone separators treated exhaust gases
3. Collection trays and dikes to minimize losses to floor drains

Physical/Chemical Forms of Uranium in Effluents: UO_3, UO_2, UCl_4, and $UO_2(NO_3)_2$.

Monitoring/Sampling Data Availability:
Limited monitoring data for indoor air sampling in buildings 9202, 9203, and 9206 are available. Disposal records for beta operations are summarized in accountability records (Compere et al. 1991).

Release Estimates Available? Miscellaneous Tennessee Eastman reports have been requested from Y-12 Central Files. Thirty-nine thousand kilograms or 23 curies of normal uranium were reportedly released to EFPC from 1943 to 1945 (Griffith 1957). Other reports contain additional uranium loss estimates (Compere et al 1991).

Accidental Releases Documented? Numerous accidental releases were reported to have occurred during the war effort. Documents that describe amounts released per accident were not available. Accidental releases were combined with reported releases (Griffith 1957).

Information Relevant to Estimating Releases: Medical and Chemical division reports for 1944 - 1948 contain monitoring results for air sampling general indoor air and process exhaust stacks (Smith et al. 1945; Berggren 1947). Accountability discard records of potential uranium loss quantities to air and surface water are available, but were not used during the Task 6 evaluation. Tennessee Eastman reports for 1948 through 1952 were identified from a bibliography listing, but were not located during the Task 6 investigation. If found, the Tennessee Eastman reports may be useful for future evaluations in a dose reconstruction study.

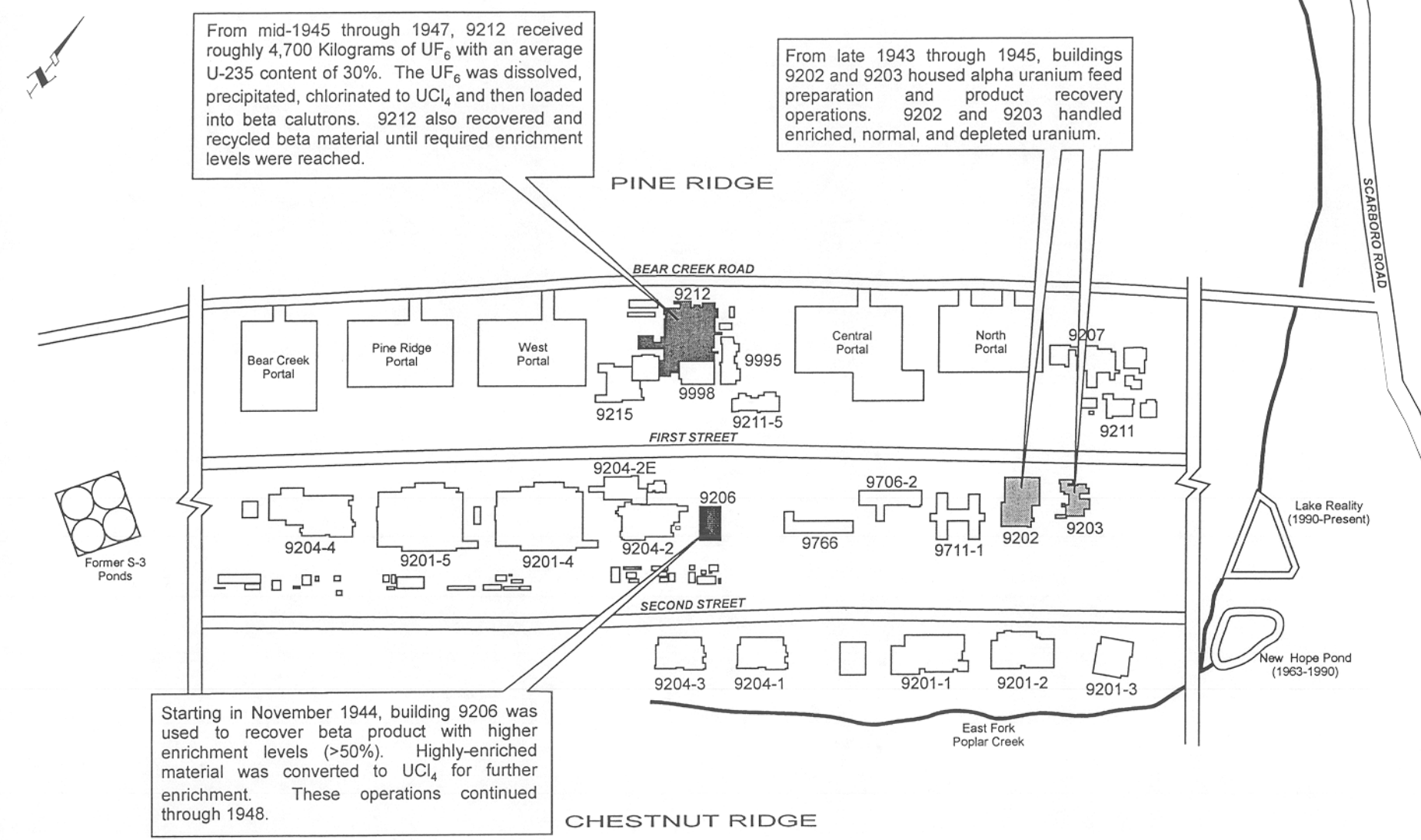

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FIGURE A-2

FEED PREPARATION AND PRODUCT PROCESSING FACILITIES
(1943 - 1947)

KEY URANIUM OPERATION: Uranium Recovery and Recycle

See FIGURE A-3

Brief Description of Operations, Forms of Uranium Handled:
Following World War II, Y-12 ceased uranium enrichment operations and reduced its workforce from 55,000 to 1,500. Except for limited activities associated with pilot-scale uranium weapon development, Y-12's main production operations centered around uranium recovery and recycling of residual uranium found on equipment and scrap material associated with Y-12's alpha and beta production operations or on material shipped from the Atomic Energy Commission's Weldon Spring site located in Missouri. Operations included mechanical scraping and brushing, nitric acid washing, and distillation and recovery of solid uranium compounds adhered to surfaces. Releases to the off-site environment came from contaminated scrap, sewer water, and ventilation or process exhaust stacks. Uranium-contaminated materials included condensates, scrubber solutions, raffinates, destructive distillates, oils, and miscellaneous residues. These facilities handling mostly normal and depleted uranium. These types of operations continued during Y-12's weapon component manufacturing years (1950s to 1990s).

Dates of Operation: 1945 - 1951

Buildings Involved: 9202, 9203, 9206, and 9212

Mechanisms for Release of Uranium to the Air:

1. Scraping and brushing operations released particulates through exhaust stacks.
2. Uranium from chemical recovery operations released through exhaust stacks/vents.
3. Muffle furnaces released vapors and particulates through scrubbers and filtered stacks.

Mechanisms for Release of Uranium to Surface Waters:

1. Depleted and normal uranium acid washes released to storm drains/sewers and EFPC
3. Surface runoff from contaminated, uranium recovery and conversion areas.

Effluent Treatment Provided:

1. Caustic/wet scrubbers on chemical conversion exhaust stacks and vents.
2. Roughing filters and rotoclone separators for conversion and incinerator stack exhausts.

Physical/Chemical Forms of Uranium in Effluents: UO_4, UO_3, UO_2, $UO_2(NO_3)_2$, and U_3O_8

Monitoring/Sampling Data Availability:

1. Limited monitoring data for 1945 to 1950 and release estimates of uranium through general building ventilation and process exhaust stacks are available in industrial hygiene or medical section reports.
2. Accountability discard records dated between late 1948 and 1952 are available.

Release Estimates Available?

1. Classified and unclassified versions of a historical radionuclide release reports (Owings et al. 1986; Griffith 1957) are available.
2. Other reports contain release estimates that are based on studies conducted in 1944 through 1946 for 9206 and 9202 and material accountability records (Smith et al. 1945; McLendon 1946).

Accidental Releases Documented?
Descriptions of accidents have only been provided through interviews with retired workers. 1946 to 1951 releases to EFPC from Building 9206 were frequent and reportedly resulted in large pH changes (~2 to ~12).

Information Relevant to Estimating Releases:

1946 - 1953 monitoring data for indoor air and exhaust stacks (Smith et al. 1945; Berggren 1947) are available. Accountability discard records are available, but were not used for the Task 6 investigation. Tennessee Eastman reports for 1948 through 1952 were identified from a bibliography listing, but were not located during the Task 6 investigation. If found, the Tennessee Eastman reports may be useful for future evaluations in a dose reconstruction study.

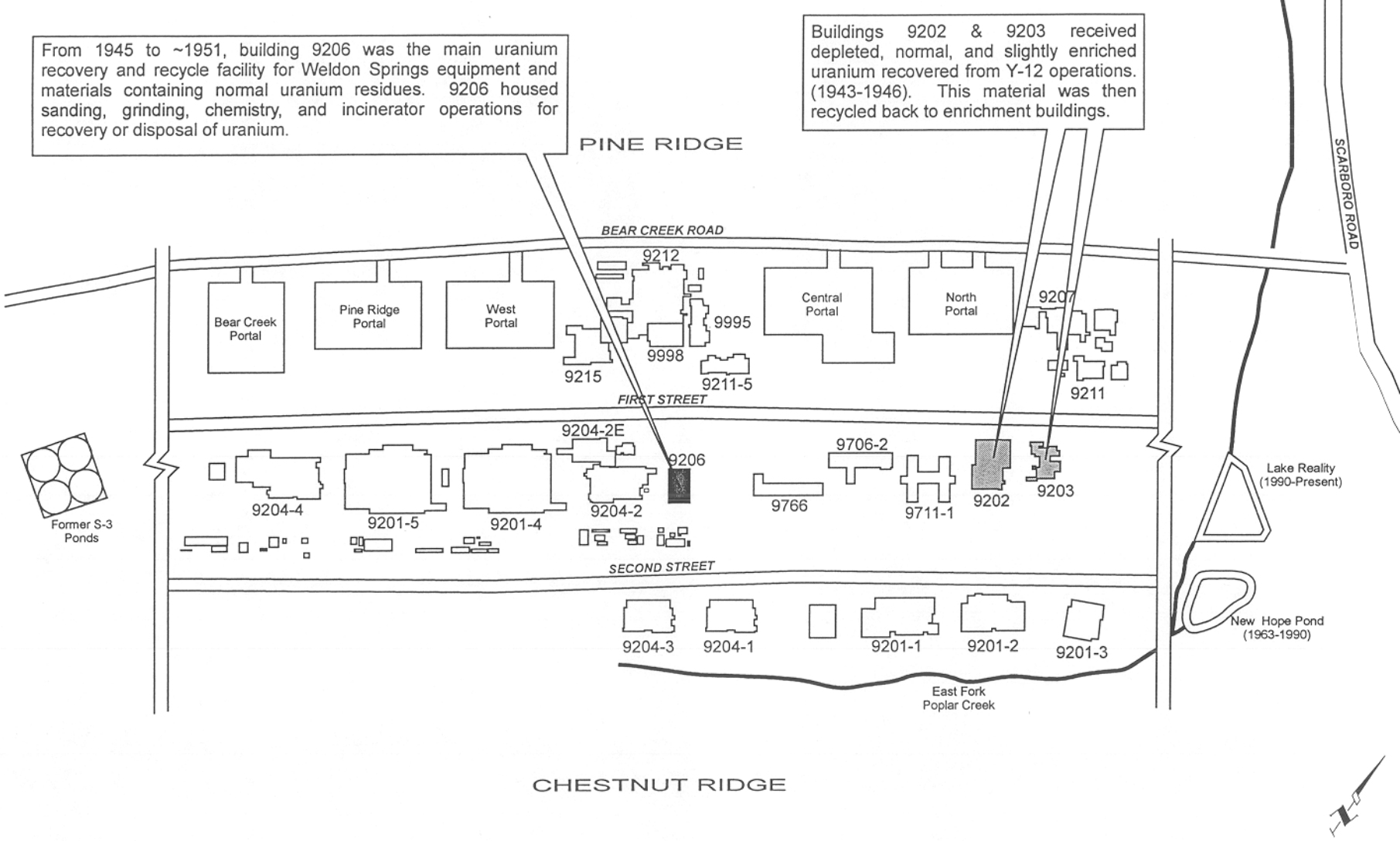

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FIGURE A-3

URANIUM RECOVERY AND RECYCLE FACILITIES

(1945 - 1951)

KEY URANIUM OPERATION: Uranium Salvage

See FIGURE A-4

Brief Description of Operations, Forms of Uranium Handled:
During and after World War II, Y-12 salvage operations involved recovery of uranium from materials not considered production equipment. Other materials included liquid and solid waste materials from maintenance/cleanup activities such as mop water, laundry washes, and floor drain residues. Combustible materials such as wood, leather, rags, sponges, filter paper, and carbon solids were burned in muffle furnaces and incinerators to recover uranium. Air was pulled through a furnace to a scrubbing tower for removal of tar and condensables, cooled, and then passed through a cotton filter and rotoclone prior to release. The scrubbing tower was made of a chemical ceramic (Ceretherm) and packed with one inch Pyrex Raschig rings. One rotoclone served five furnace/scrubbing tower operations. Other salvage operations included mechanical scraping and brushing, nitric acid washing, and distillation and recovery of uranium compounds. During the war, if the salvaged uranium was of economic value it was converted to UCl_4 for enrichment purposes.

Buildings 9207 and 9211 provided salvage for alpha operations. Building 9206 provided salvage for beta operations. Releases to the off-site environment came from contaminated scrap, sewer water, and ventilation or process exhaust stack releases. Uranium-contaminated materials included condensates, scrubber solutions, raffinates, destructive distillates, oils, and miscellaneous residues and particulates. These types of operations continued during Y-12's weapon component manufacturing years (1950s to 1990s).

Dates of Operation: 1945 - 1951

Buildings Involved: 9206, 9207, and 9211

Mechanisms for Release of Uranium to the Air:

1. Filtered muffle furnace exhaust systems (periodically monitored).
2. Uncontrolled uranium released general building ventilation (periodically monitored).

Mechanisms for Release of Uranium to Surface Waters:

1. Acid washes, laundry waters, mop water released to storm drains and EFPC (periodically monitored)
2. Surface runoff from areas contaminated due to recovery operations (unmonitored)

Effluent Treatment Provided:

1. Scrubber tower on muffle furnace stacks/vents.
2. Cotton/glass wool filters for chemical operations and muffle furnace stacks/vents.

Physical/Chemical Forms of Uranium in Effluents: UO_3, UO_2, and $UO_2(NO_3)_2$

Monitoring/Sampling Data Availability:

1. Limited air monitoring data for 9206 is available for 1945 - 1951.
2. Periodic indoor air sampling data for 1948 and 1949 are available for 9207 and 9211.

Release Estimates Available? Classified and unclassified versions of a historical radionuclide release report (Owings et al. 1986; Griffith 1957). Release estimates for this period are based on studies conducted during the time period 1945 to 1951 (Smith et al. 1945; Berggren 1947).

Accidental Releases Documented? Descriptions of accidents have only been provided through interviews with retired workers (West 1995). Reportedly, larger releases occurred during alpha operations in buildings 9207 and 9211. Releases from beta operations in 9206 were kept low.

Information Relevant to Estimating Releases: Use of published 1946 and 1947 studies which describe losses of uranium through air and water (Smith et al. 1945; Berggren 1947). Tennessee Eastman reports for 1948 through 1952 were identified from a bibliography listing, but were not located during the Task 6 investigation. If found, the Tennessee Eastman reports may be useful for future evaluations in a dose reconstruction study.

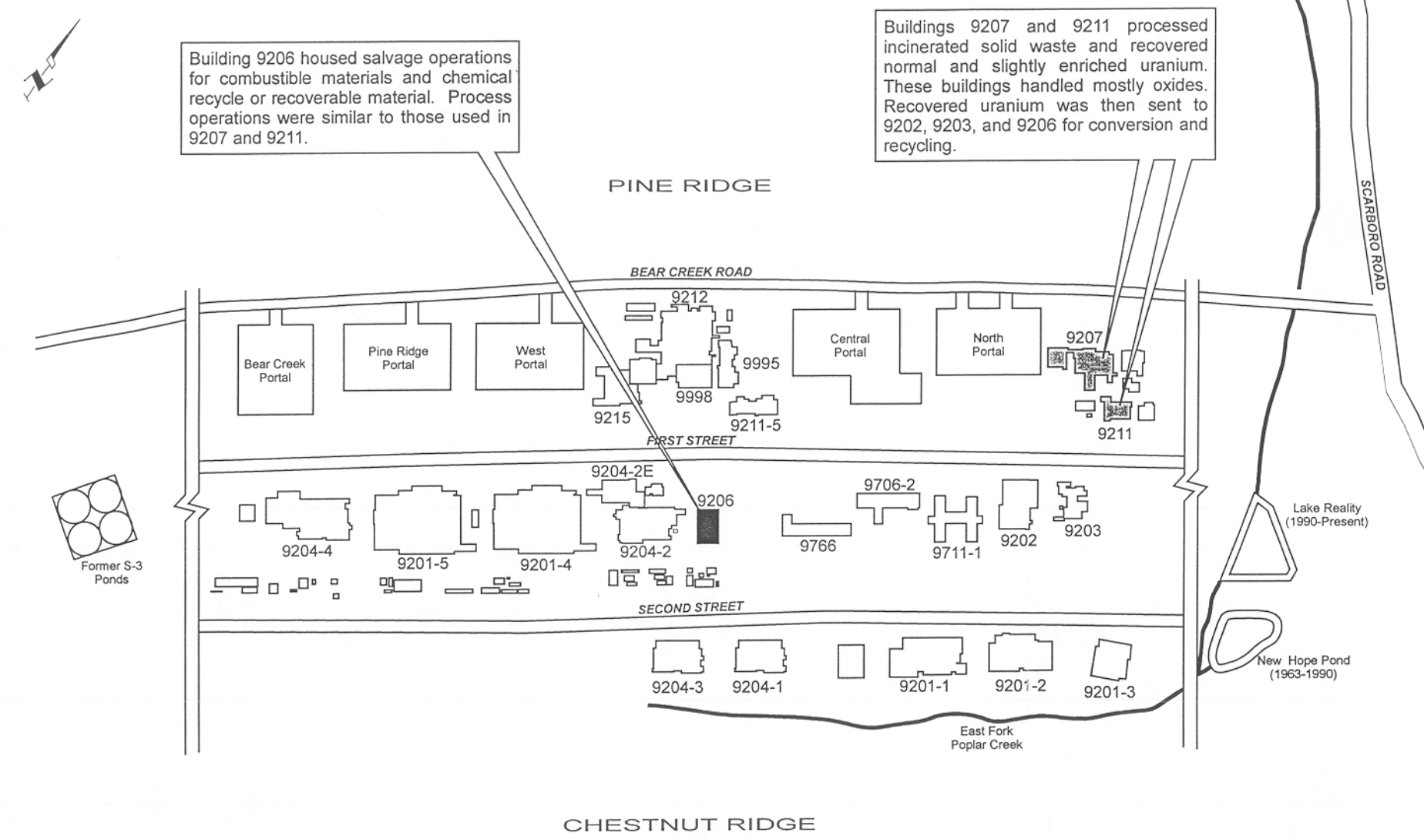

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FIGURE A-4

URANIUM SALVAGE FACILITIES

(1947 - 1951)

KEY URANIUM OPERATION: Uranium Preparation/Recycle

See FIGURE A-5

Brief Description of Operations, Forms of Uranium Handled: Starting approximately in 1952, Y-12 began a continuous growth into uranium weapon component manufacturing operations handling a variety of uranium compounds and enrichment. Enriched uranium prepared for reduction to metal involved conversion of UF_6 to UF_4, purification of uranyl nitrate solutions, precipitation for uranium recovery, and then reduction to uranium metal. The majority of these processes were housed in buildings 9206 and 9212. Buildings 9202 and 9203 were used for pilot-scale uranium process design and improvements prior to implementation into 9206 and 9212 production streams. After 1964, conversion of UF_6 was no longer needed due to sufficient U.S. stockpile of weapon-grade, enriched uranium. As a result, 9206 and 9212 housed uranium recover, purification, recycle operations, and metal preparation up into the 1990s. Releases to the off-site environment came from contaminated scrap, sewer water, and ventilation or process exhaust stack releases. Uranium-contaminated materials included airborne particulates, condensates, scrubber solutions, raffinates, destructive distillates, oils, and miscellaneous residues.

Dates of Operation: 1952 - 1995

Buildings Involved: 9202, 9206, 9211, and 9212

Mechanisms for Release of Uranium to the Air:

1. Uncontrolled releases from various operations to building vents (routinely monitored).
2. Solid/combustible incinerator filtered exhaust systems (routinely monitored).
3. Chemical conversion of UF_6 and recovery operations released through scrubber systems and filtered exhaust systems (Enriched uranium: routinely monitored; depleted uranium: periodically monitored).

Mechanisms for Release of Uranium to Surface Waters:

1. Conversion operations released uranium to drains, usually < 10 ppm (monitored).
2. Recovery operations released solutions to drains and EFPC (routinely monitored).
3. Surface runoff from contaminated areas (unmonitored)

Effluent Treatment Provided:

1. Conversion operations released uranium to caustic/wet scrubbers and filtered stacks.
2. Salvage operations released uranium to rotoclones, roughing filters, and absolute filtered stacks.
3. Recovery and purification released raffinates to filtered exhaust stacks.
4. Waste solutions with nonrecoverable uranium were dumped in acid ponds.

Physical/Chemical Forms of Uranium in Effluents: UO_3, $UO_2(NO_3)_2$, UF_6, UO_2F_2, UF_4, and metal

Monitoring/Sampling Data Availability: Stack monitoring data is available in the 1950's. 1950's stack monitoring data and estimates of losses of airborne and waterborne uranium were found in early health physics reports. Stack monitoring data for 1957 to 1988 was reviewed and incorporated into the Task 6 source term evaluation.

Release Estimates Available? Classified and unclassified versions of historical radionuclide release reports (Owings et al. 1986; Griffith 1957). Monthly health physics reports and accountability records are available.

Accidental Releases Documented? Descriptions of accidents are found in various documents and from interviews with retired workers (Owings et al. 1986). The 1958 criticality accident is well documented in Y-12 reports, but only resulted in minor releases of uranium (McLendon 1958). The 1958 accident involved small amounts of uranium and believed to be associated with only small releases of radionuclides to outdoor environment.

Information Relevant to Estimating Releases: Routine stack release data (1950s to 1990) reported in monthly health physics reports and on archived computer tapes were used in the Task 6 evaluation. Release estimates for these years were calculated based on monitoring data for individual stacks.

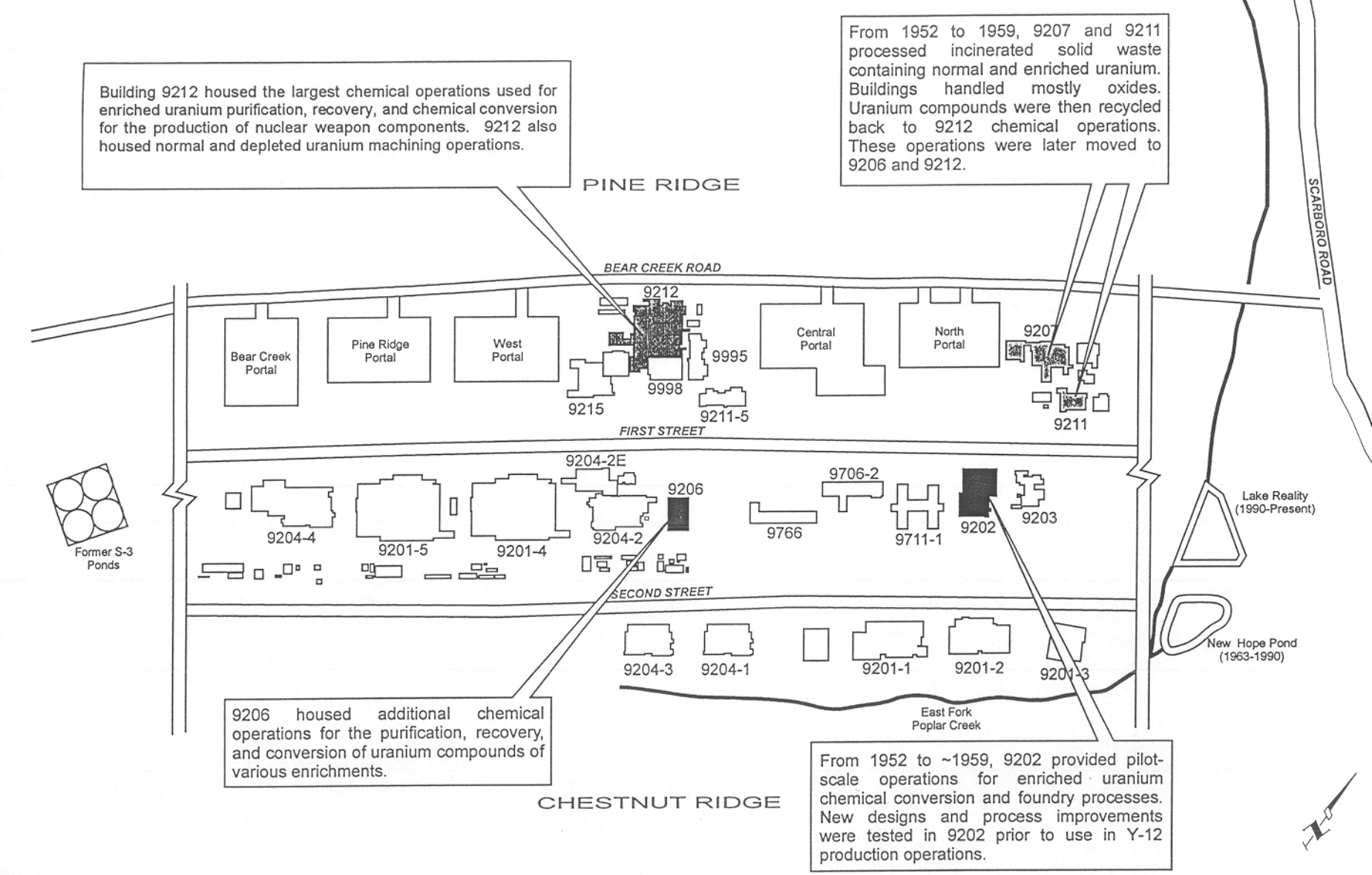

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FIGURE A-5

URANIUM PREPARATION AND RECYCLE FACILITIES

(1952 - 1995)

KEY URANIUM OPERATION: Uranium Forming/Machining

See FIGURE A-6

Brief Description of Operations, Forms of Uranium Handled: By late 1952, Y-12 had an elaborate set of operations capable of casting, rolling, and machining uranium metal. These operations handled enriched, normal, and depleted uranium. Uranium was pressed, rolled, shaped, and machined into finished weapon components. Most of these operations took place in the buildings listed below. From 1948 to the late 1950s, 9202 provided additional foundry and rolling and milling operations. Releases to the off-site environment were from sewer water and ventilation or process exhaust stack releases. Uranium-contaminated materials that were released included airborne particulates and vapors, oils, and miscellaneous residues.

Dates of Operation: 1952 - 1995

Buildings Involved: 9201-5, 9204-4, 9215, and 9998

Mechanisms for Release of Uranium to the Air:

1. Uncontrolled material released to general building ventilation (ambient air routinely monitored for normal, deleted, and enriched uranium operations).
2. Particulates, vapors, and fumes generated from routine rolling, milling, and machining operations and infrequent small fires released uranium to filtered exhaust systems (enriched stacks routinely monitored; depleted stacks periodically monitored).
3. Degreasing and acid washing/pickling operations released vapors and particulates to scrubbers and filtered stack exhausts (enrich stacks routinely monitored; depleted stacks periodically monitored).

Mechanisms for Release of Uranium to Surface Waters

1. Depleted and enriched uranium acid pickling wash solutions released to storm drains and EFPC; 10 ppm limit for solutions released to EFPC (each production batch monitored)
2. Surface runoff from contaminated areas (unmonitored)

Effluent Treatment Provided:

1. Rotoclone or roughing filters for depleted uranium stack exhausts.
2. High-efficiency filters for enriched uranium stack releases.
3. Caustic/wet scrubbers for uranium salvage and recovery operations.

Physical/Chemical Forms of Uranium in Effluents: metal, UO_3, UO_2, and $UO_2(NO_3)_2$

Monitoring/Sampling Data Availability:

1. Stack monitoring data for 1953 to 1988 is available on archived computer tapes. Monthly stack release quantities based on daily stack sampling results are also available.
2. Daily EFPC surface water sampling results starting in the mid 1950s.

Release Estimates Available?

1. Classified and unclassified versions of historical radionuclide release reports (Owings et al. 1986; Griffith 1957) are available.
2. Monthly health physics reports and accountability records that contain uranium release estimates are available.

Accidental Releases Documented? Descriptions of accidents were found in various documents and from interviews with retired workers (Griffith 1956; Owings et al. 1986). Release estimates were not available during the Task 6 investigation.

Information Relevant to Estimating Releases: Routine surface water and stack release data reported in monthly health physics reports and electronic data files were used to estimate uranium releases.

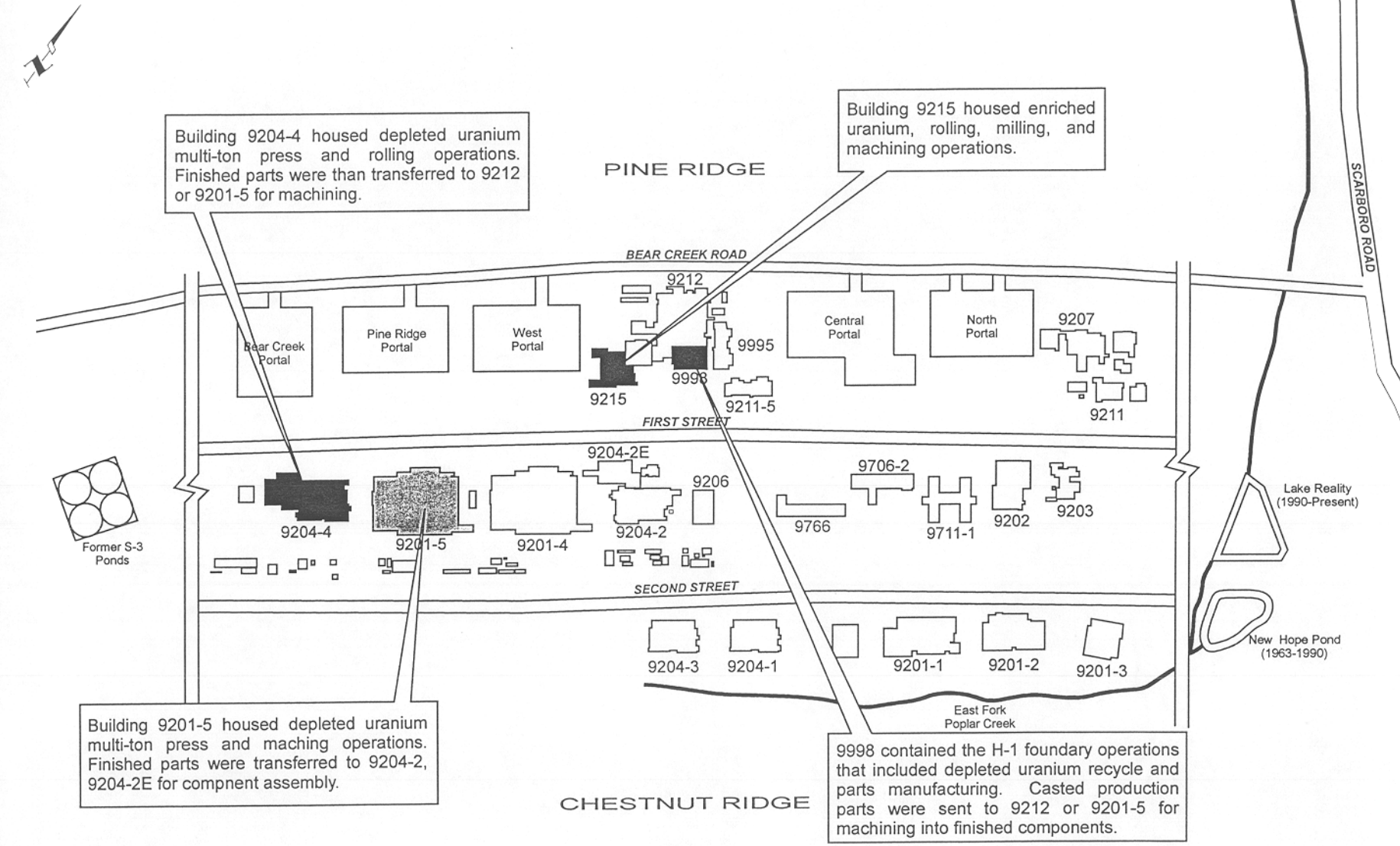

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FIGURE A-6

URANIUM FORMING AND MACHINING FACILITIES

(1952 - 1995)

KEY URANIUM OPERATION: Uranium Component Assembly

See FIGURE A-7

Brief Description of Operations, Forms of Uranium Handled: Starting in 1952, Y-12 brought on-line final weapon component assembly operations in buildings 9202, 9204-2, and 9204-2E. Machined components were sent through finishing operations that included drilling, welding, brazing, polishing and final specification checks. Building 9202 was primarily used for early pilot-scale operations that involved design and implementation of fabrication and assembly processes and final inspection procedures. Assembly operations generally were not associated with significant releases of uranium compounds. Any measurable amounts of uranium were recovered and recycled back into the production stream. Uranium was routinely recovered from articles such as rags, paper towels, oils, and liquid waste products. Process exhaust stacks were equipped with HEPA filtration and periodically inspected for buildup of uranium.

Dates of Operation: 1952 - 1995

Buildings Involved: 9202, 9204-2, and 9204-2E

Mechanisms for Release of Uranium to the Air:

1. Uranium particulates release through filtered exhaust stacks as a result of welding, drilling, brazing, and polishing operations (periodically monitored).
2. Uranium particulates released through filtered exhaust stacks as a result of infrequent upset conditions such as fires or explosions (periodically monitored).

Mechanisms for Release of Uranium to Surface Waters:

1. None identified to date

Effluent Treatment Provided:

1. HEPA filters on process stack exhausts

Physical/Chemical Forms of Uranium in Effluents: uranium metal and oxides

Monitoring/Sampling Data Availability:

Sporadic stack monitoring data starting in 1954 were found on computer tapes and selected health physics reports.

Release Estimates Available? Classified and unclassified versions of a historical radionuclide release report (Owings et al. 1986). Monthly health physics reports, accountability records, and other reports were useful for estimating Y-12 uranium releases (Owings et al. 1986; Griffith 1957).

Accidental Releases Documented? None identified during the Task 6 investigation.

Information Relevant to Estimating Releases: Stack release data (1954 - 1994) reported in selected health physics reports or archived on computer tapes were used for the Task 6 source term development. Quarterly totals were calculated from individual stack sample results to estimate uranium airborne releases from Y-12 assembly operations.

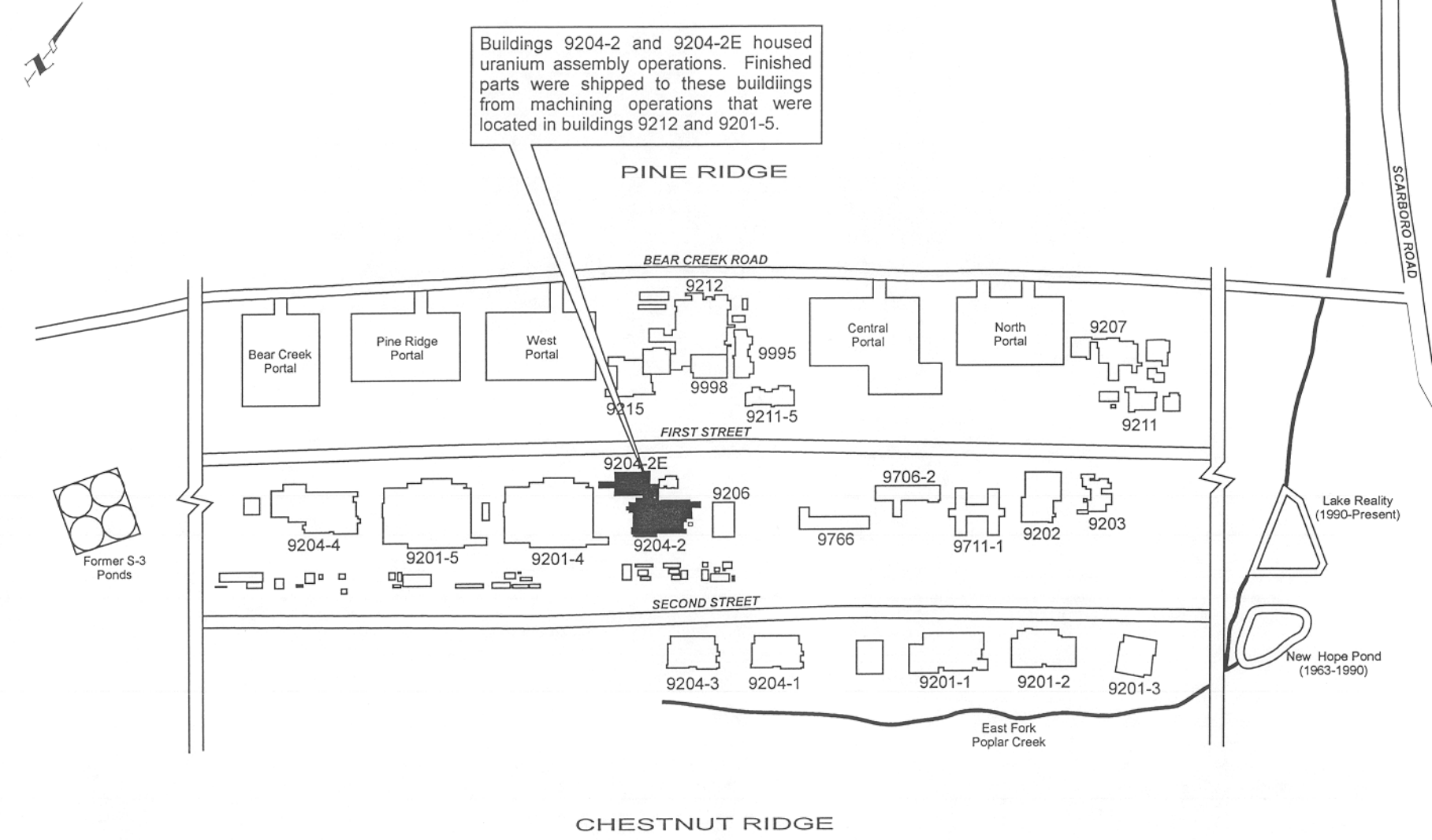

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FIGURE A-7

URANIUM COMPONENT ASSEMBLY FACILITIES
(1952 - 1995)

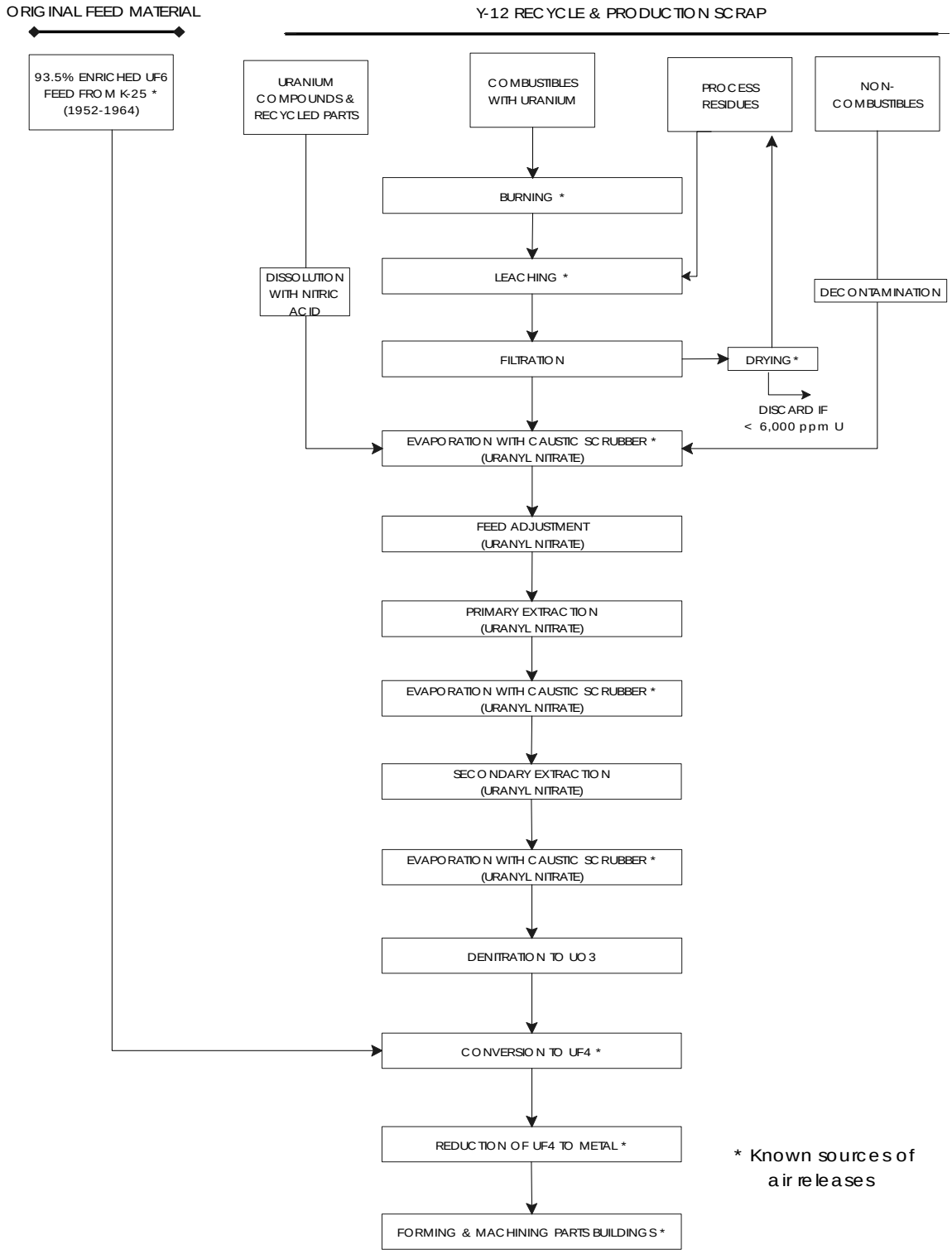

Figure A-8: Y-12 Enriched Uranium Preparation and Recovery Operations Buildings 9212, 9206, and 9215 (Patton et al. 1963)

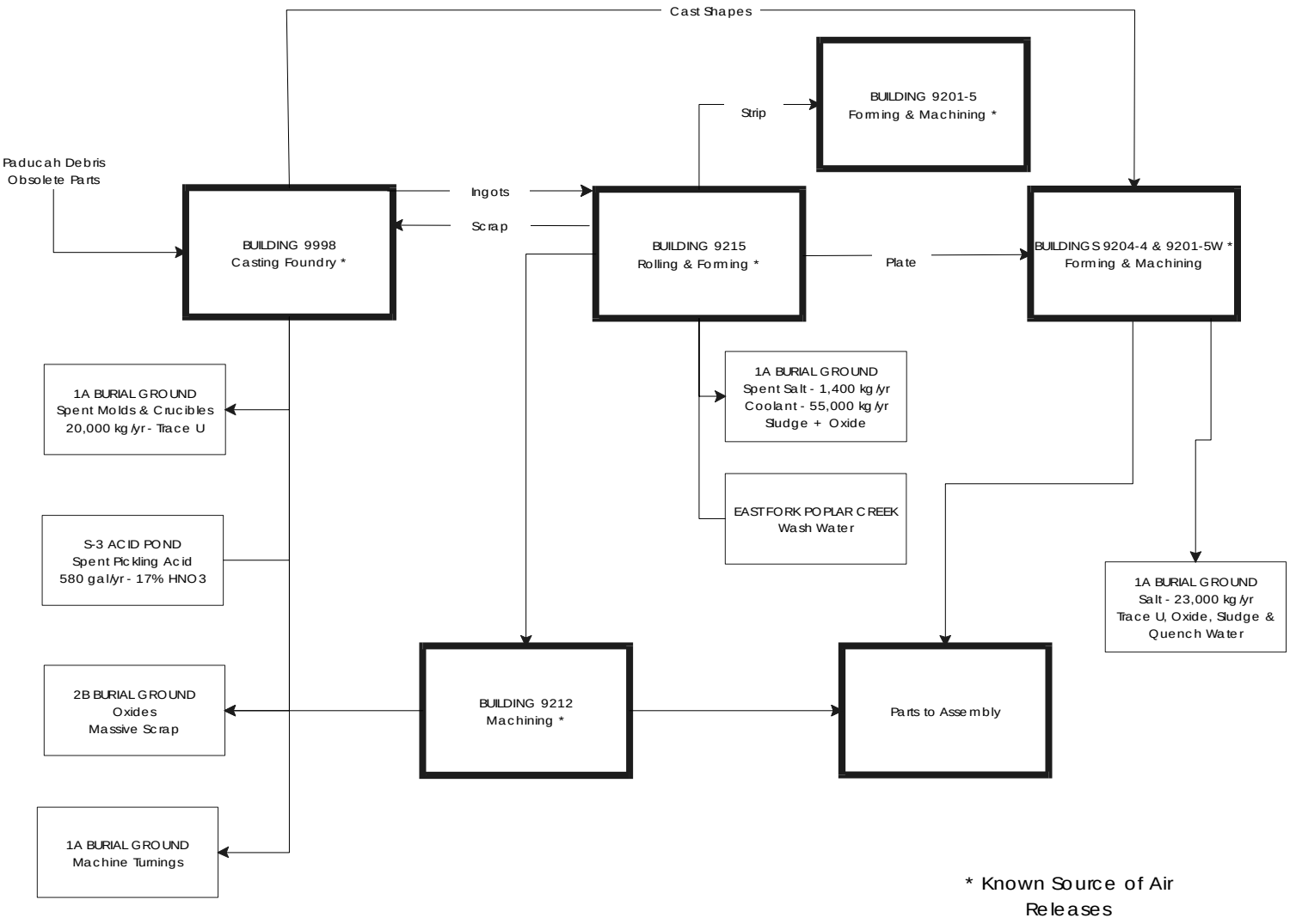

Figure A-9: Y-12 Depleted Uranium Process Operations (Patton et al. 1963)

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APPENDIX B

DESCRIPTIONS OF KEY URANIUM OPERATIONS AT K-25/S-50

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This appendix contains descriptions of historical K-25 and S-50 uranium process operations and locations and mechanisms within those operations that released uranium to the off-site environment. The reader can develop an understanding of K-25 and S-50 uranium operations, and key release sources, through a series of maps that highlight specific buildings and their functions and tables that discuss further the role of each building or process. The S-50 liquid thermal diffusion plant operated for one year and then shut down. However, during its operation, it released rather substantial amounts of uranium to the atmosphere and to the Clinch River. K-25's mission remained the same from 1945-1985. Unlike Y-12, which had a series of elevated exhaust stacks and vents, K-25 airborne effluents were largely released inside the gaseous diffusion process buildings and passed to the outdoor atmosphere through a series of vents located on the walls and roofs of the buildings. The majority of these airborne releases occurred absent of routine effluent monitoring. The role of each building is shown in the tables and figures of this appendix.

The following pages provide descriptions of the various uranium processing operations at the K-25/S-50 complex, along with a series of figures that highlight the buildings that were responsible for both uranium airborne releases and releases to surface water. The operations, and the buildings involved, are summarized in Table B-1.

Table B-1
Buildings at the K-25/S-50 Complex Involved in Uranium Operations

Uranium Operation	K-25/S-50 Buildings Involved
Gaseous Diffusion Enrichment	K-25, K-27, K-29, K-31, K-33
UF_6 Feed Manufacturing	K-1131
Feed Vaporization	K-131, K-1131
Product and Tails Withdrawal	K-413, K-631, K-1131
Uranium Decontamination and Recovery	K-131, K-1301, K-1302, K-1303, K-1401, K-1410, K-1420, K-1421
Hydrogen Fluoride and Fluorine Disposal	K-1405
Research and Development	K-633, K-1303, K-1413
Laboratory Services	K-1004-A, K-1004-J, K-1004-L
Toll Enrichment	K-1423
Gas Centrifuge Program	K-1200, K-1225, K-1210
Liquid Thermal Diffusion (S-50)	F-01, F-05, F-07, F-08

KEY URANIUM OPERATION: Gaseous Diffusion Enrichment

See FIGURE B-1

Brief Description of Operations, Forms of Uranium Handled:
Natural, partially depleted, and slightly enriched uranium hexafluoride (UF_6) in the form of gas was fed into the diffusion cascade, ultimately producing UF_6 with a higher concentration of the U-235 isotope at the top of the cascade. UF_6 depleted in the U-235 isotope was discharged at the bottom of the cascade. As the UF_6 gas was pumped through a porous barrier, the lighter U-235 isotope passed through more rapidly than the heavier U-238 isotope. To achieve the desired enrichment, the UF_6 gas was pumped through many stages. As of 1983, the cumulative inventory of the cascade feeds indicate the facility handled 206,353,541 kilograms of uranium and 1,832,962 kilograms of U-235 over the 39-year period of operation.

Dates of Operation: Highly enriched: 1945- 1964; Lower enrichment: 1964-1985

Buildings Involved : K-25, K-27, K-29, K-31, and K-33

Mechanisms for Release of Uranium to the Air:

1. Routine purging of light gases (process was monitored prior to filtering and release. Release estimates were not made by DOE)
2. Equipment evacuations prior to maintenance activities (unmonitored)
3. Failure or overloading of traps and absorbers; trap replacement (unmonitored)
4. Insufficient equipment evacuations prior to maintenance (unmonitored)
5. Cylinder ruptures and valve failures (unmonitored)
6. Equipment failure such as valves, pumps, compressors, barrier, etc. (unmonitored)
7. Development of plugs of UF_6 in drain and evacuation and sample lines (unmonitored).
8. Valving errors (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Scrubber solution blowdown
2. Very dilute decontamination solutions from building interior
3. Rainwater runoff from building

Effluent Treatment Provided:

1. Alumina traps, carbon absorbers, and later caustic scrubber on purge cascade exhaust
2. Sodium fluoride traps on wet air evacuation systems
3. Alumina traps on seal exhaust systems

Physical/Chemical Forms of Uranium in Effluents:

UF_6 converted to UO_2F_2 in the atmosphere.

Monitoring/Sampling Data Availability:

1. Purge cascade data 1945-1984

Accidental Releases Documented?

Limited information was located in materials accountability

Information Relevant to Estimating releases:

1. Limited amount of indoor air sampling data
2. Limited information concerning building out leakage (expected to be small)

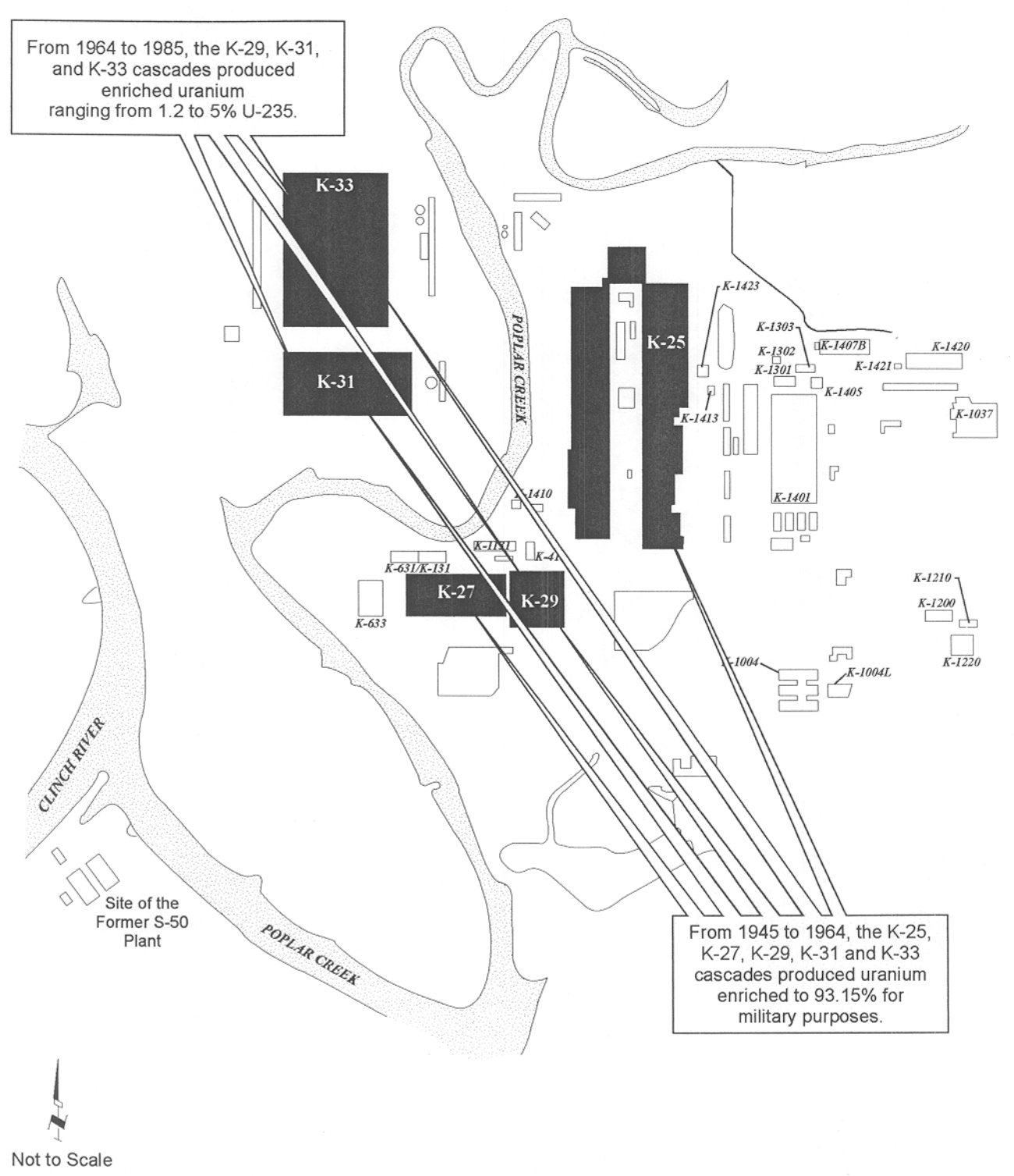

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FIGURE B-1

GASEOUS DIFFUSION ENRICHMENT CASCADE

KEY URANIUM OPERATION: UF_6 Feed Manufacturing

See FIGURE B-2

Brief Description of Operations, Forms of Uranium Handled:

Gaseous uranium hexafluoride (UF_6) was the chemical fed to the gaseous diffusion cascade. Feed manufacturing was the process that made the gaseous UF_6. UF_6 was made at K-25 by converting uranium dioxide (UO_2) first to uranium tetrafluoride and then to uranium hexafluoride. The uranium dioxide was reacted with hydrogen fluoride gas in a vibrating tray reactor. The uranium tetrafluoride was then collected in a hopper and fed to another vibrating tray reactor and fluorinated to uranium hexafluoride. The uranium hexafluoride gas stream was passed to cold traps, where approximately 75% of the uranium hexafluoride condensed out. The rest of this gas was recycled. The vibrating tray technology was eventually replaced with flame tower reactors in 1955. By 1957 the tower reactors had been modified by screw-fed tower reactors.

The feed manufacturing facility experienced many operating problems, resulting in unmonitored releases of uranium hexafluoride to the atmosphere. The loss of uranium as uranium trioxide and uranium tetrafluoride are also known to have occurred (ORGDP 1985). The process handled natural, depleted, and slightly enriched uranium.

Dates of Operation: 1952-1961 and 1962-1965

Buildings Involved: K-1131

Mechanisms for Release of Uranium to the Air:

1. Overloaded cold traps and ruptures (unmonitored)
2. Feed cylinder ruptures and valve leaks and ruptures (unmonitored)
3. Routine exhaust of HF and F_2 gases containing trace quantities of UF_6 (unmonitored)
4. Losses in transferring material from conversion processes (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Discard of decontamination solution to K-1407B holding pond (monitored)
2. Building runoff (unmonitored)

Effluent Treatment Provided:

Cold traps for air exhausted to stack.

Physical/Chemical Forms of Uranium in Effluents:

1. UF_6 converted to UO_2F_2 in the atmosphere
2. UO_2 (powder), and
3. UF_4

Monitoring/Sampling Data Availability:

1. Summary exhaust stack data for 1955-1961 time period
2. Indoor air sampling data are available throughout the lifetime of the plant.

Accidental Releases Documented?

Uranium accountability records appear to capture some accidents.

Information Relevant to Estimating releases:

1. Material release estimates from uranium accountability.
2. Special studies carried out by health physics in 1961.
3. Indoor air sampling.

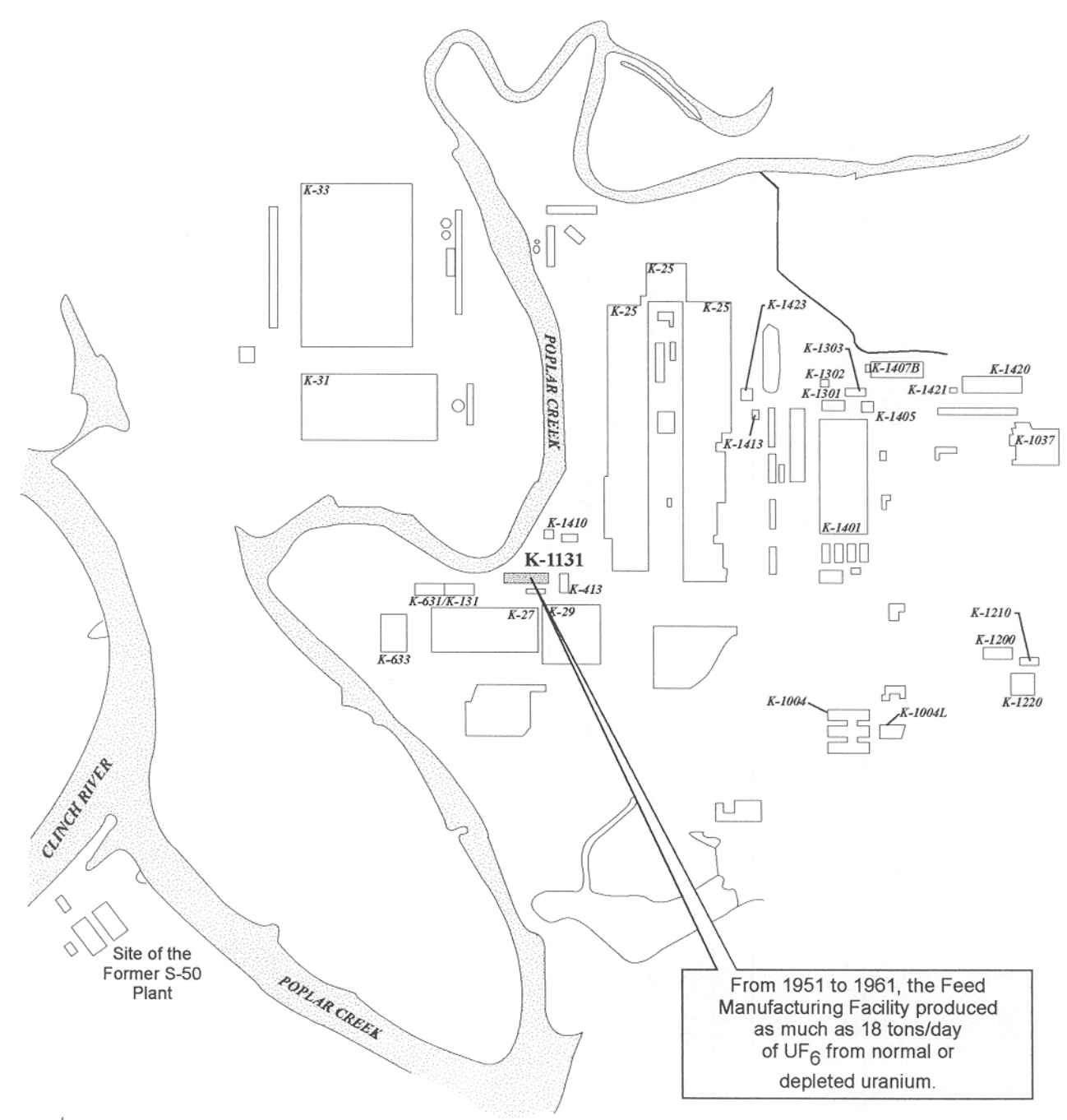

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FIGURE B-2

FEED MANUFACTURING FACILITY

KEY URANIUM OPERATION: Feed Vaporization

See FIGURE B-3

Brief Description of Operations, Forms of Uranium Handled:
Feed Vaporization Facilities heated cylinders containing solidified UF_6 to convert the material to vapor for feeding to the cascade. The feed material consisted of UF_6 from natural assay material (0.71% U-235) or slightly enriched (to 2% U-235). Prior to 1952, feed material was shipped to the ORGDP from the manufacturer and introduced to the cascade at the K-131 feed facility. After 1952, the feed material was received in 2.5, 10, and 14-ton cylinders from the Paducah Gaseous Diffusion Plant and transported to K-131, K-33, or K-1131 facilities. From interim storage the cylinders were moved to the scale for weighing before going to the feed vaporization autoclave. The autoclave was among the most important components in regards to safe handling of UF_6. During feed operations UF_6 existed in liquid and vapor phases considerably above atmospheric pressure. The potential for the greatest amount and highest rate of release existed when UF_6 in large cylinders was in the liquid phase with vapor pressure considerably above atmospheric.

Dates of Operation: 1945-1985

Buildings Involved: K-131 and K-1131

Mechanisms for Release of Uranium to the Air:

1. Faulty cylinder connections (unmonitored)
2. Cylinder and valve ruptures (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Discard of decontamination solution to K-1407B holding pond (monitored K-1131)
2. Rainwater runoff from building (unmonitored)
3. Drainage to Poplar Creek (unmonitored - K-131)

Effluent Treatment Provided:

1. Cold traps for air exhausted to stack (K-1131)
2. Vent gases, evacuation vapors, and blowdowns were fed to the bottom of spray towers before venting to the atmosphere (K-131).

Physical/Chemical Forms of Uranium in Effluents:

UF_6 converted to UO_2F_2 in the atmosphere.

Monitoring/Sampling Data Availability:

1. K-1131 summary exhaust stack data for the 1955-1961 time period
2. Indoor air sampling data for both buildings

Accidental Releases Documented?

Many releases were captured in uranium accountability records.

Information Relevant to Estimating releases:

1. Air monitoring (limited)
2. Uranium accountability records.
3. Indoor air sampling

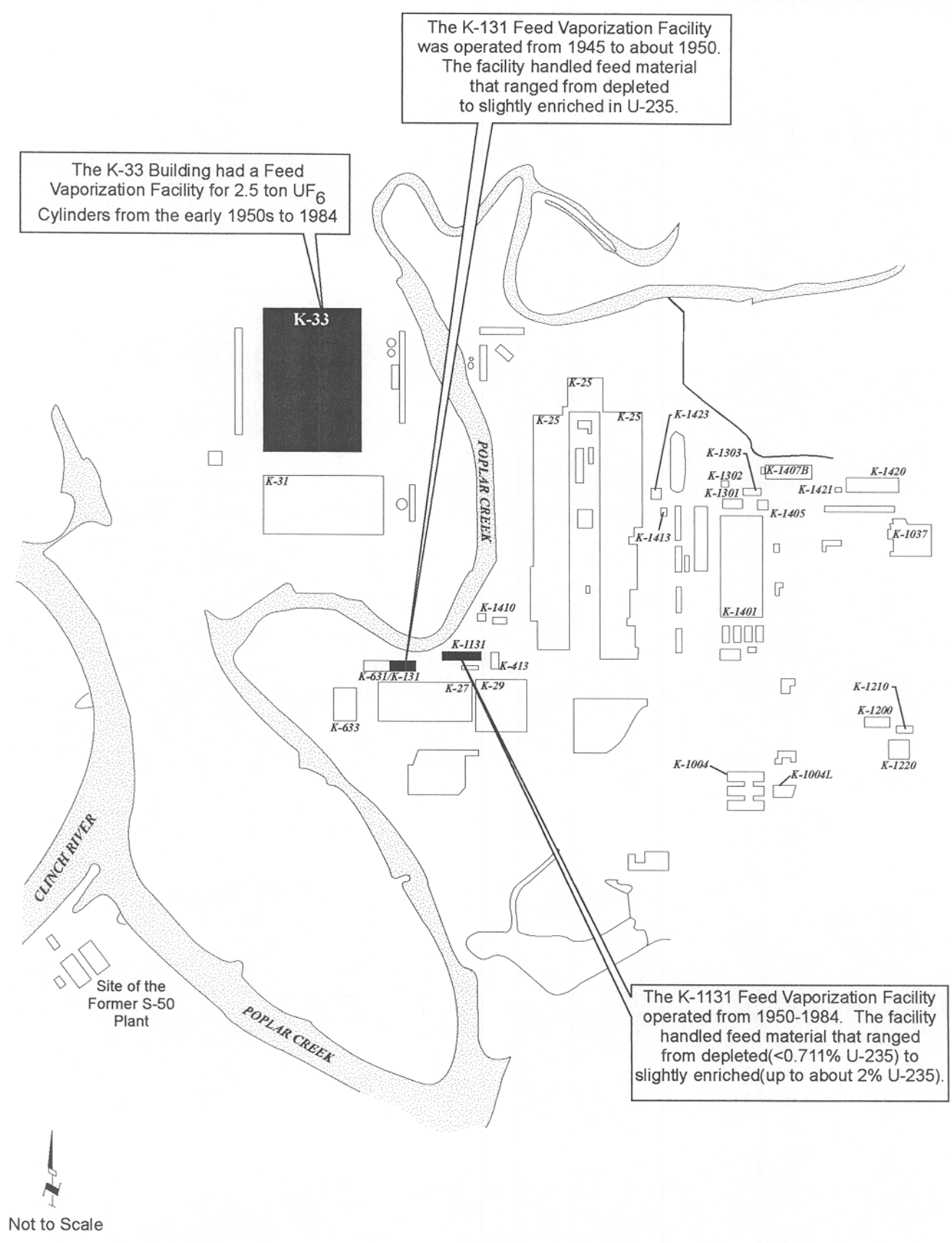

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FIGURE B-3

FEED VAPORIZATION FACILITIES

KEY URANIUM OPERATION: Product and Tails Withdrawal

See FIGURE B-4

Brief Description of Operations, Forms of Uranium Handled:
Gaseous UF_6 product and tails were removed from the cascade at the product and tails withdrawal facilities. In these facilities, gaseous UF_6 was compressed and condensed into a liquid and drained into transport cylinders. The cylinders were transported to a cooling area, where the contents solidified prior to transport to their final destination.

In the tails facilities, gaseous UF_6 depleted in U-235, was removed from the "stripping stages" at the bottom of the cascade and distributed to the tails withdrawal facilities by intra plant piping. The U-235 enrichment of tails was less than 0.711%.

In the product withdrawal facilities, gaseous UF_6 enriched in U-235, was removed from the enriching section at the top of the cascade and distributed to the product withdrawal facilities by intra plant piping. The U-235 enrichments ranged from greater than 0.711% to approximately 93.5%.

Dates of Operation: 1945-1985

Buildings Involved: K-413, K-631, and K-1131

Mechanisms for Release of Uranium to the Air:

1. Cold trap replacement (K-1131 - unmonitored)
2. Cylinder explosions or pigtail ruptures (unmonitored)
3. Pump and equipment failure (unmonitored)
4. Oil and UF_6 reactions sometimes caused explosions (unmonitored)
5. Faulty cylinder connections (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Rainwater runoff from building
2. Decontamination of building interior

Effluent Treatment Provided:

1. K-1131 - cold traps were provided for air exhausted to the stack (intermittent).
2. K-413 and K-631 information not available at this time (intermittent).

Physical/Chemical Forms of Uranium in Effluents:

UF_6 converted to UO_2F_2 in the atmosphere

Monitoring/Sampling Data Availability:

1. K-1131 (Monitoring data available 1955-1961)
2. K-1131, K-413, and K-631 indoor air sampling data

Accidental Releases Documented?

Uranium accountability records contain limited information.

Information Relevant to Estimating releases:

1. K-1131 stack sampling data
2. Indoor air sampling data

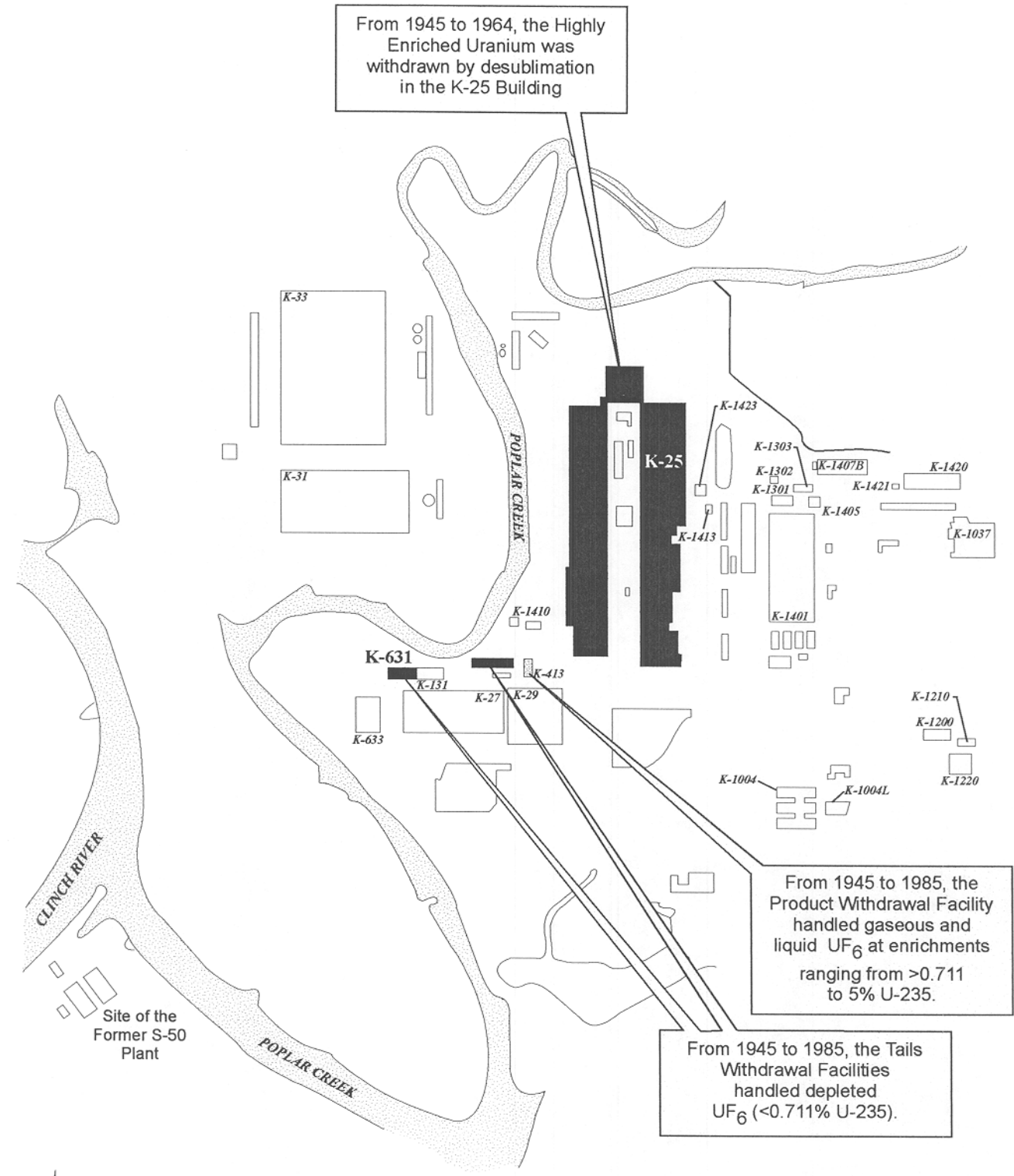

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FIGURE B-4

PRODUCT AND TAILS WITHDRAWAL FACILITIES

KEY URANIUM OPERATION: Uranium Decontamination and Recovery

See FIGURE B-5

Brief Description of Operations, Forms of Uranium Handled:
Equipment used in the gaseous diffusion process was subject to gradual deposition of uranium-bearing compounds (USDOE 1979). The primary method for cleaning the process equipment included a form of mechanical removal with cleaning solutions of water, steam, weak nitric acid, or sodium carbonate (USDOE 1979). The cleaning solutions were sampled for uranium and transported to K-131 for recovery if economic recovery criteria were met; otherwise, the solutions were discharged either directly to Popular Creek or to the K-1407B settling pond.

Uranium contaminated gloves, shoes, and oil sludge were sent to the K-1421 incinerator. The ash from the incinerator was collected leached, and processed through the uranium recovery operation at K-1231 and later K-1420.

Dates of Operation: 1944-1985

Buildings Involved: K-131, K-1301, K-1302, K-1303, K-1401, K-1410, K-1420, and K-1421

Mechanisms for Release of Uranium to the Air:

1. Routine releases from the incinerator (unmonitored - K-1421)
2. Cylinder purging and evacuation (unmonitored)
3. Cylinder ruptures, valve failures and faulty connections (unmonitored)
4. Releases due to valving errors (unmonitored)
5. Cold trap leak due to equipment failure (unmonitored)
6. Process/drain line ruptures (unmonitored)
7. Routine releases from furnace fluorinations (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Direct discharge of decontamination solutions to storm drains or Poplar Creek.
2. Discharge of solutions to K-1407B
3. Leakage of corroded storage drums
4. Leakage from corroded equipment

Effluent Treatment Provided:

1. Cold traps were provided in some areas.

Physical/Chemical Forms of Uranium in Effluents:

1. UF_6 converted to UO_2F_2 in the atmosphere
2. Solution

Monitoring/Sampling Data Availability:

1. Limited stack monitoring data for K-1420 (1961-1963)
2. Some discharge monitoring data from the K-1407B pond to Poplar Creek was available and has been reviewed.
3. Indoor air monitoring data

Accidental Releases Documented?

Limited availability from uranium accountability records.

Information Relevant to Estimating releases:

1. Stack monitoring data for K-1420
2. Discharge monitoring data from the K-1407B Pond

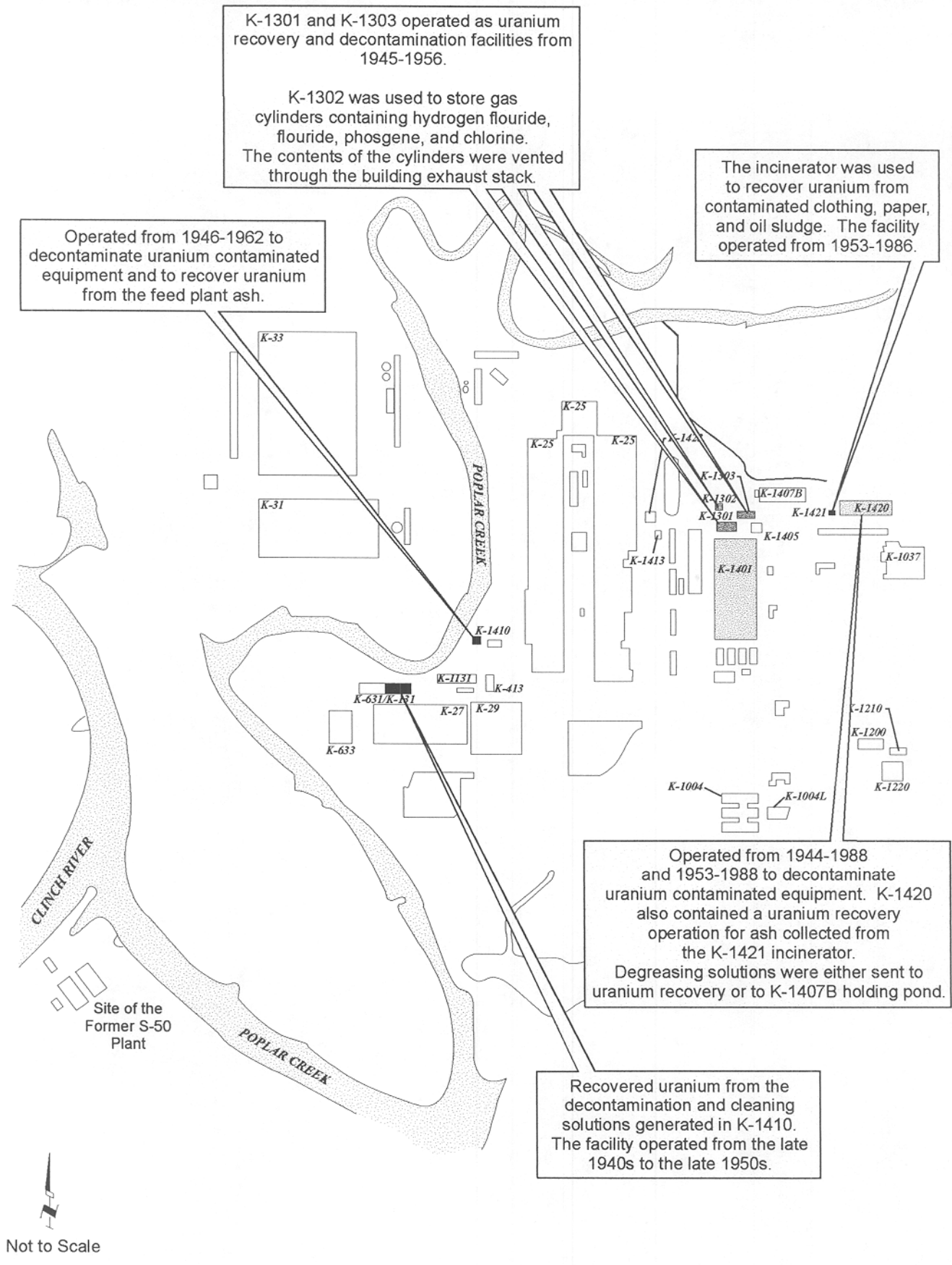

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FIGURE B-5

URANIUM DECONTAMINATION AND RECOVERY FACILITIES

KEY URANIUM OPERATION: Hydrogen Fluoride and Fluorine Disposal

See FIGURE B-6

Brief Description of Operations, Forms of Uranium Handled:

The K-1405 building operated a disposal tower to convert fluorine and hydrogen fluoride to harmless materials before venting these gases to the atmosphere. Gases disposed in this tower included excess fluorine generated in the K-1300 buildings and fluorine and hydrogen fluoride present in equipment in the process buildings and other support facilities. It was known as early as October 1945 that process gas containing UF_6 would be encountered in the fluorine gases entering the disposal plant. Uranium would precipitate partially with the caustic solution and cause plugging in pumps, lines, and instrumentation. The tower was analyzed periodically for uranium concentrations, as were solids in the settling tanks. The tower and tanks were washed down periodically to avoid accumulation of uranium that might present criticality hazards.

Cleanup of the plant involved disposal of 1,500 to 2,000 pounds of uranium and 90,000 pounds of spent carbon-alumina-uranium in a specially constructed concrete pit. No record of its subsequent removal and recovery has been found.

Dates of Operation: 1944-1952

Buildings Involved: K-1405

Mechanisms for Release of Uranium to the Air:

1. Disposal tower relief valve openings
2. Cold trap leaks or failures
3. Plugging of equipment resulted in ruptures.

Mechanisms for Release of Uranium to Surface Waters:

1. Decontamination of disposal plant equipment
2. Rainwater runoff from building

Effluent Treatment Provided:

It is known that the disposal plant used carbon alumina traps in the disposal process. However, the location of these traps in the building is still under investigation.

Physical/Chemical Forms of Uranium in Effluents:

1. UF_6
2. Sodium uranate
3. Uranyl fluoride

Monitoring/Sampling Data Availability:

No information available at this time.

Accidental Releases Documented?

Limited uranium accountability information is available.

Information Relevant to Estimating releases:

Limited uranium accountability information is available.

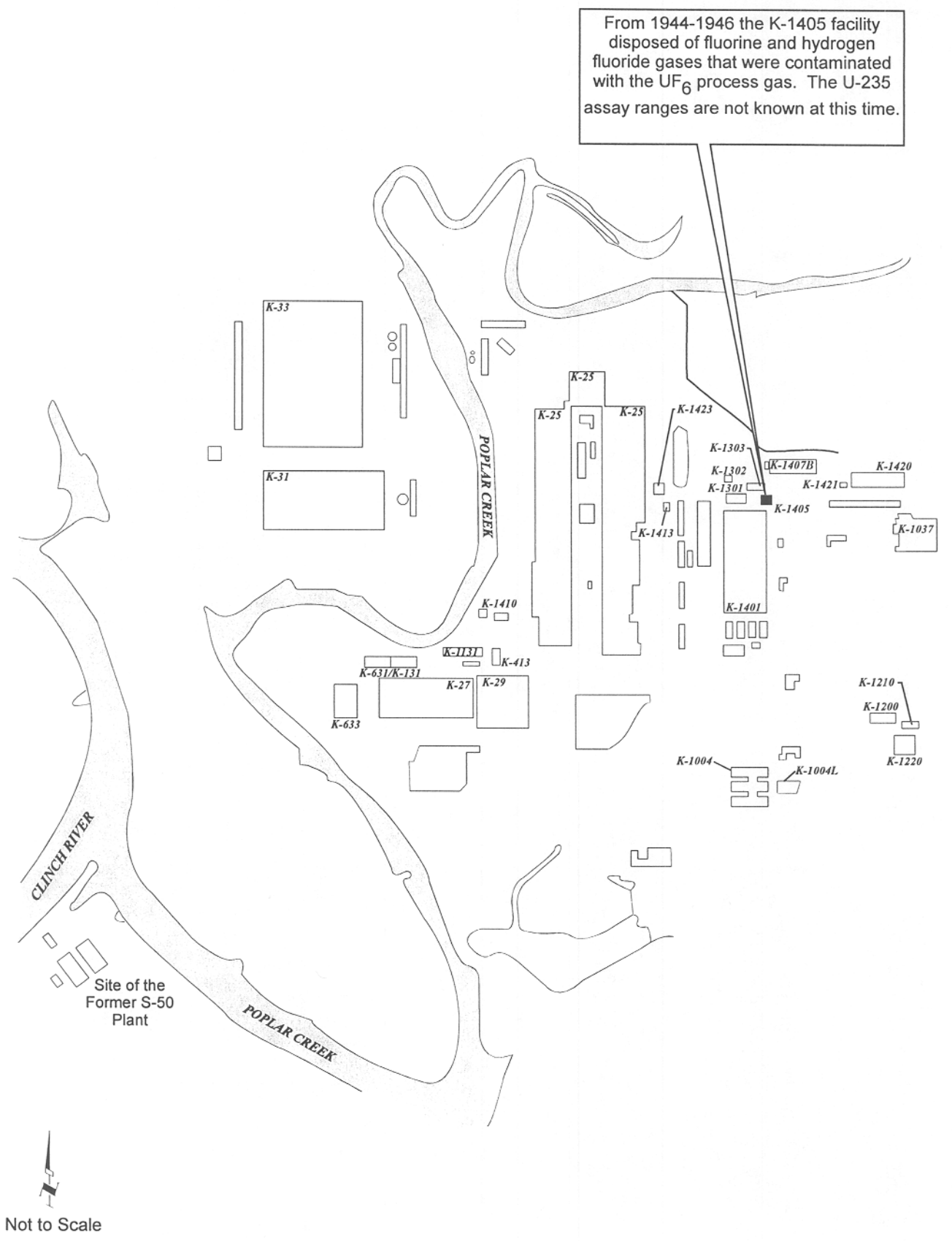

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FIGURE B-6

HYDROGEN FLUORIDE AND FLUORINE DISPOSAL FACILITY

KEY URANIUM OPERATION: Research and Development

See FIGURE B-7

Brief Description of Operations, Forms of Uranium Handled:

Research and Development activities were a vital part of the K-25 operations. Some of the activities included:

- Fluorination of uranium metal chips to UF_6 (K-1413)
- Processing of zirconium-clad depleted and enriched uranium oxide (K-1413)
- Compressor testing (K-1413)
- Uranium chemistry research (K-1413)
- Equipment performance tests (K-633)
- Compressor testing (K-1303)

Dates of Operation: 1944-1985

Buildings Involved: K-633, K-1303, and K-1413

Mechanisms for Release of Uranium to the Air:

1. Ruptured process lines (unmonitored)
2. Equipment evacuations (unmonitored)
3. Cylinder and valve ruptures (unmonitored)
4. Overloaded traps (unmonitored)
5. Equipment failure such as pumps, valves, and seals (unmonitored)
6. Corroded equipment leaks (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Until 1974-1975 the K-1413 waste streams discharged into pits on the north and east side of the building. From these pits the wastes were discharged to the sewer systems.
2. After 1974-1975 the wastes were pumped from the north and east pits to the K-1407B holding pond (K-1413).

Effluent Treatment Provided:

1. K-1413 had a gas scrubber for airborne effluents
2. Two alumina traps were connected to the seal exhaust system (K-633)

Physical/Chemical Forms of Uranium in Effluents:

1. UF_6 converted to UO_2F_2 in the atmosphere (K-1413, K-633, K-1303)
2. Uranium in solution

Monitoring/Sampling Data Availability:

Not known at this time

Accidental Releases Documented?

Limited information available from uranium accountability

Information Relevant to Estimating releases:

Limited information from uranium accountability

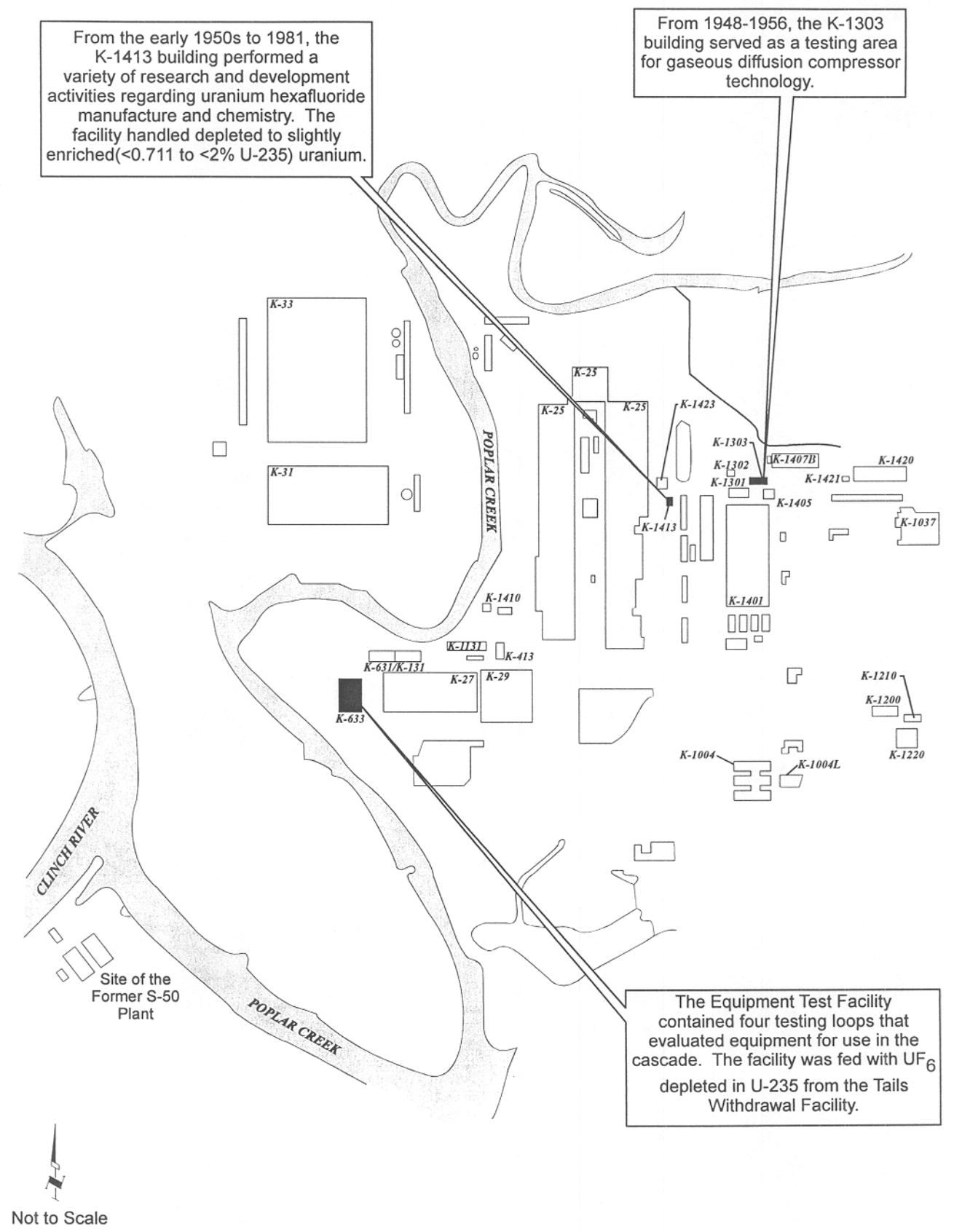

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FIGURE B-7

RESEARCH AND DEVELOPMENT FACILITIES

KEY URANIUM OPERATION: Laboratory Services

See FIGURE B-8

Brief Description of Operations, Forms of Uranium Handled:

The K-1004 laboratory complex was used to support cascade and research and development operations at the K-25 Site. The various types of activities in the labs are listed below.

- Uranium hexafluoride samples from the processing areas are analyzed in the plant labs for U-235 and purity. As a result, an inventory of 3,000 to 4,000 pounds of UF_6 was maintained at the labs, primarily for assay standards. Most of the material was depleted or normal UF_6 assay, but some enriched material was stored.
- The Enrichment Technology Facilities were located primarily in the K-1004-L building and contained equipment and facilities for the development and testing of cascade barrier material. The Barrier Preparation section, the Barrier Services section, and the Cascade Pilot Plant are housed in this building. The pilot plant was a small scale diffusion cascade operated to test and characterize barrier materials. Feed for the pilot plant was supplied from UF_6 cylinders that contained natural assay UF_6.
- The K-1004-J Laboratory was designed as a facility for research and development work on the recovery of uranium from the Hanford operations spent fuel solutions.

Dates of Operation: 1944- 1985

Buildings Involved: K-1004-A, K-1004-J, K-1004-L

Mechanisms for Release of Uranium to the Air:

1. Overfilled sample cylinders (unmonitored)
2. Faulty cylinder connections (unmonitored)
3. Sample cylinders rupture or valve failures (unmonitored)
4. Pump seal failures (unmonitored)
5. Laboratory hood releases (unmonitored)
6. Purging of light gases (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

Waste stream drainage from the laboratory complex entered retention pits prior to combining with the storm drain system. The storm drain system discharged to the K-1070B Pond.

Effluent Treatment Provided:

Not known at this time.

Physical/Chemical Forms of Uranium in Effluents:

1. UF_6 converted to UO_2F_2 in the atmosphere
2. Uranium in solution

Monitoring/Sampling Data Availability:

Not known at this time.

Accidental Releases Documented?

Some releases were reported by Uranium Accountability Department

Information Relevant to Estimating releases:

Information from the Uranium Accountability Department

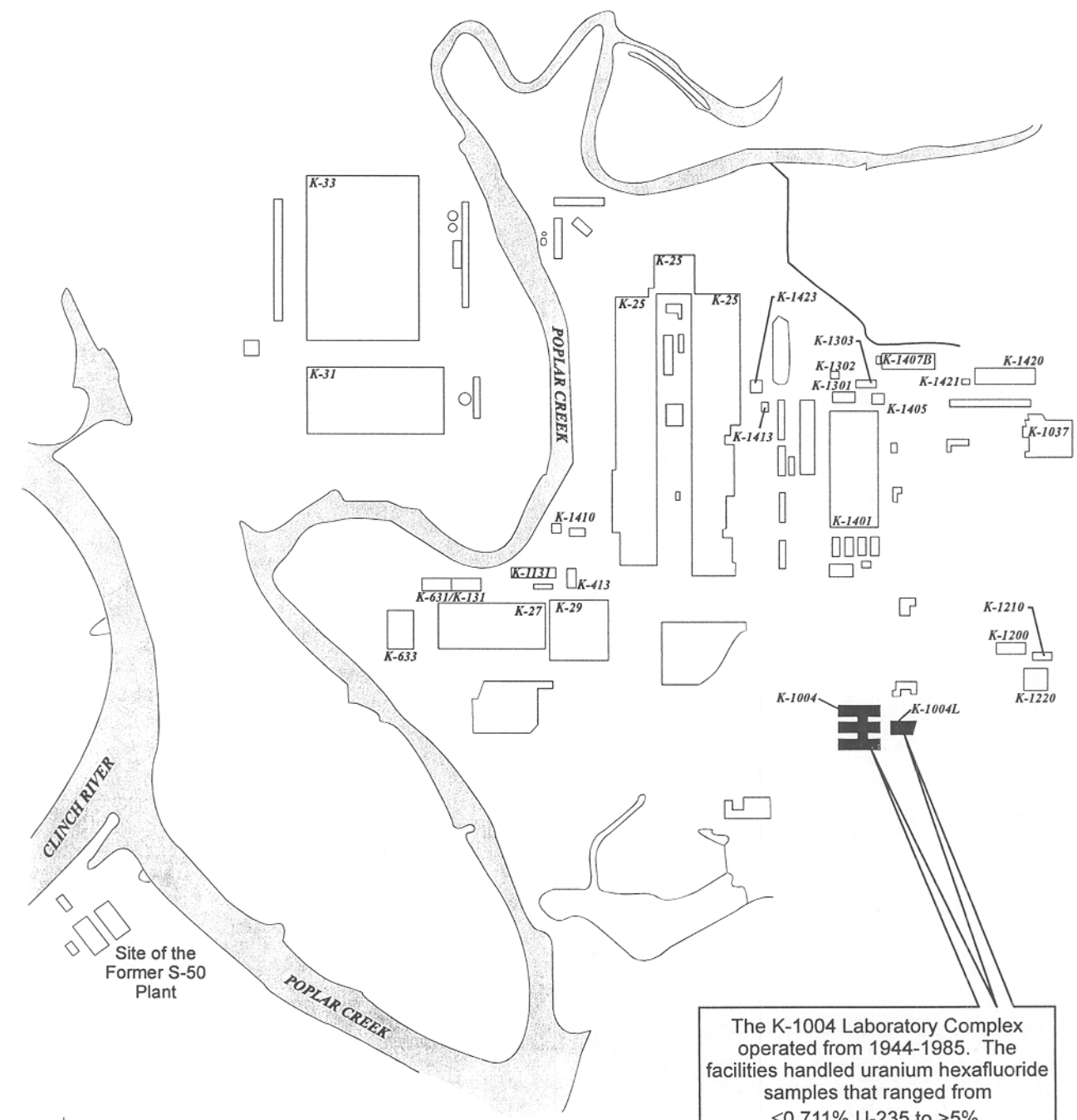

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FIGURE B-8

SUPPORT LABORATORIES

KEY URANIUM OPERATION: Toll Enrichment

See FIGURE B-9

Brief Description of Operations, Forms of Uranium Handled:

The Toll Enrichment Facility was placed into operation in January 1969 as a shipping and receiving point for private industry owners of UF_6 who sought uranium enrichment services from the K-25 Site for fueling of light water nuclear power reactors. K-1423 received 10 or 14 ton cylinders from the K-413 Product Withdrawal Facility filled with solidified UF_6 product. The cylinders were placed in autoclaves and heated to convert the UF_6 to a liquid. Samples were then withdrawn and sent for analysis to the K-1004 Laboratory to assure compliance (impurity, assay, etc.) with the enrichment services contract. The liquid UF_6 was then transferred to customer-owned 2.5-ton product cylinders and the contents allowed to solidify by ambient cooling. After weighing, the cylinders were shipped to the customer and the empty 10 and 14 ton cylinders were returned to K-413 for refilling. From 1969 -1983 a total of 13,297 2.5 ton product cylinders were shipped to private industry.

Dates of Operation: 1969-1985

Buildings Involved: K-1423

Mechanisms for Release of Uranium to the Air:

1. Cylinder and pigtail ruptures (unmonitored)
2. Faulty cylinder connection (unmonitored)
3. Overfilled sample cylinders (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Rainwater runoff from building

Effluent Treatment Provided:

Not known at this time

Physical/Chemical Forms of Uranium in Effluents:

UF_6 converted to UO_2F_2 in the atmosphere.

Monitoring/Sampling Data Availability:

Effluent data do not appear to have been gathered for this facility. There is a limited amount of indoor air sampling data available.

Accidental Releases Documented?

Some information from uranium accountability records.

Information Relevant to Estimating releases:

Information from uranium accountability records were reviewed.

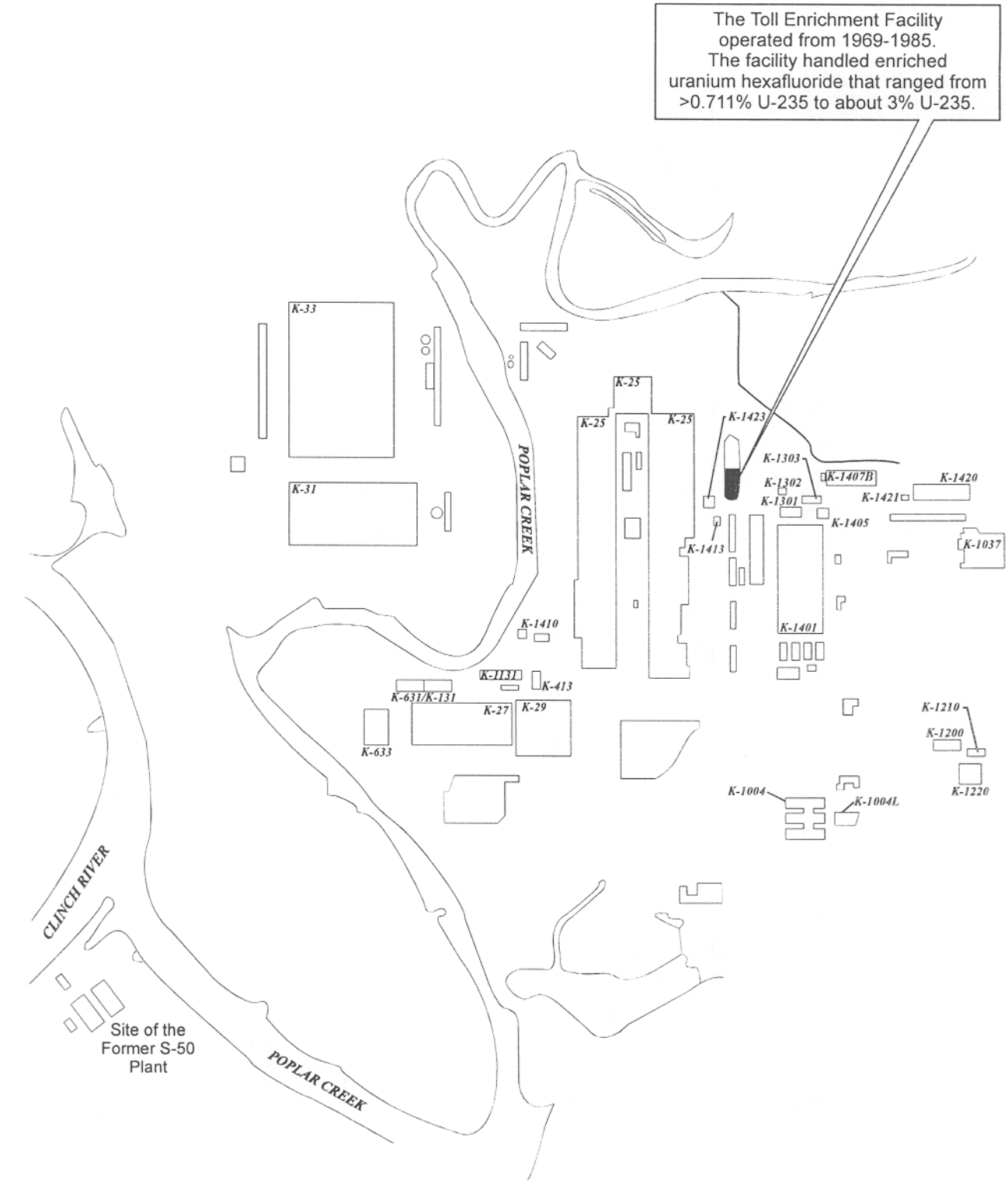

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FIGURE B-9

TOLL ENRICHMENT FACILITY

KEY URANIUM OPERATION: Gas Centrifuge Program

See FIGURE B-10

Brief Description of Operations, Forms of Uranium Handled:

In the gas centrifuge process, gaseous uranium hexafluoride is sent through high-speed centrifuges where the heavier U-238 settles to the walls of the centrifuge and the lighter U-235 to the centrifuge center. Although a single centrifuge can obtain a degree of enrichment many times that of a gaseous diffusion stage, A number of centrifuges in series (a cascade) are needed to obtain reactor-grade uranium.

The Gas Centrifuge program operated from the early 1960s to the mid-1980s. The centrifuge technology for separating uranium isotopes was originally proposed in the WWII era, however, the centrifuge machines were not strong enough to withstand the high-speeds required to separate the uranium isotopes. In the 1960s the feasibility of the process was demonstrated and small machines were successfully cascaded. In the 1970s the Centrifuge program grew with the addition of six facilities. The facilities included the Equipment Test Facility (ETF) (1971), the Advanced Machine Development Laboratory (AMDL), the Component Preparation Laboratory (CPL) (1974), the Advanced Equipment Test Facility (AETF) (1978), the Component Test Facility (CTF) (1975), and the Demonstration Facility (1982). The ETF was used to examine the reliability of four types of centrifuges. The AMDL was used to improve and test centrifuges. The CPL was used to aid in the development and demonstration of techniques for manufacturing centrifuges. The AETF was used to test the reliability of production centrifuges. The CTF was used to test the operability of the centrifuges. The Demonstration Facility was used to demonstrate the operability of the centrifuge cascades and equipment on a pilot-scale level.

Dates of Operation: Early 1960s to the late-1980s

Buildings Involved: K-1200, K-1225, K-1210

Mechanisms for Release of Uranium to the Air:

1. Equipment leaks
2. Off gas from treatment of waste

Mechanisms for Release of Uranium to Surface Waters:

1. Waste from uranium decontamination operations

Effluent Treatment Provided:

Alumina traps
Uranium Recovery operations (from alumina traps)
Settling Pond (liquid wastes)

Physical/Chemical Forms of Uranium in Effluents:

UF_6 converted to UO_2F_2 in the atmosphere.
Uranium oxide dusts

Monitoring/Sampling Data Availability:

A limited amount of sampling data were collected. However, most reported releases are engineering estimates.

Accidental Releases Documented?

Material release forms and tables found in accountability records

Information Relevant to Estimating releases:

Uranium accountability records for accidental releases and Annual reports for the site total.

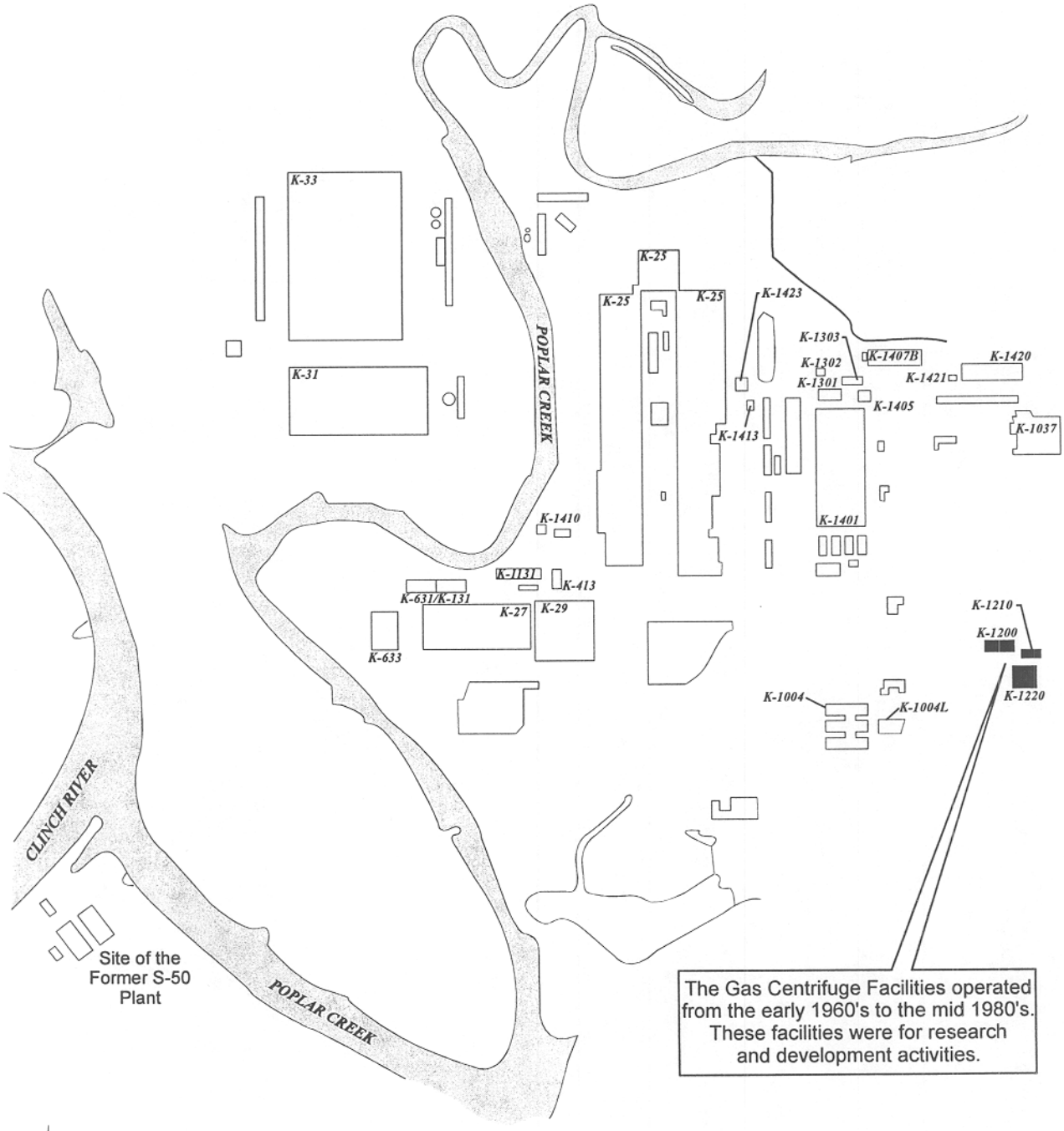

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FIGURE B-10

GAS CENTRIFUGE FACILITIES

KEY URANIUM OPERATION: Liquid Thermal Diffusion (S-50)

See FIGURE B-11

Brief Description of Operations, Forms of Uranium Handled:

A liquid thermal diffusion plant was designed and built by H.K. Ferguson Co. to determine the economic and technical feasibility of this method of separating U-235 from U-238. The plant was built on about 37 acres of land on the Clinch River near the K-25 Power House. The plant operated from October 1944 to September 1945. Normal assay (0.711% U-235) liquid UF_6 was fed to the process. The plant enrichment likely never exceeded 1.0%. The plant produced an average of 95 pounds of enriched UF_6 in November and December 1944. Production increased in Spring 1945 and peaked in June 1945 at 12,730 pounds of UF_6. Concerns about the heavy losses of UF_6, which had grown steadily since the plant began operation, led to the decision to shut down the plant. The F-01 main process building was disassembled and likely buried in the burial ground at the "Y" formed by State Routes 58 and 95. It was reported that the building contained heavy coatings of UO_2F_2 on both the inside and the outside of the roof, on the structural steel, housings, and inside duct work.

Dates of Operation: 1944-1945

Buildings Involved: F-01, F-05, F-07, and F-08

Mechanisms for Release of Uranium to the Air:

1. Equipment conditioning exhausts (unmonitored)
2. Withdrawal of product leaks and spills from plug failures (unmonitored).
3. Leaking equipment due to thermal expansion (unmonitored)
4. Vacuum system discharges during equipment evacuations (unmonitored)
5. Spills from transfer operations (unmonitored)

Mechanisms for Release of Uranium to Surface Waters:

1. Decontamination of building and equipment (unmonitored)
2. Steam condensate (unmonitored)
3. Rainwater runoff from building (unmonitored)

Effluent Treatment Provided:

None

Physical/Chemical Forms of Uranium in Effluents:

UF_6 converted to UO_2F_2 in the atmosphere.

Monitoring/Sampling Data Availability:

A small number of storm drain water samples collected two years after the S-50 shut down.

Accidental Releases Documented?

Not available at this time.

Information Relevant to Estimating releases:

1. Limited indoor air sampling information
2. Limited uranium accountability information
3. Limited material loss estimates

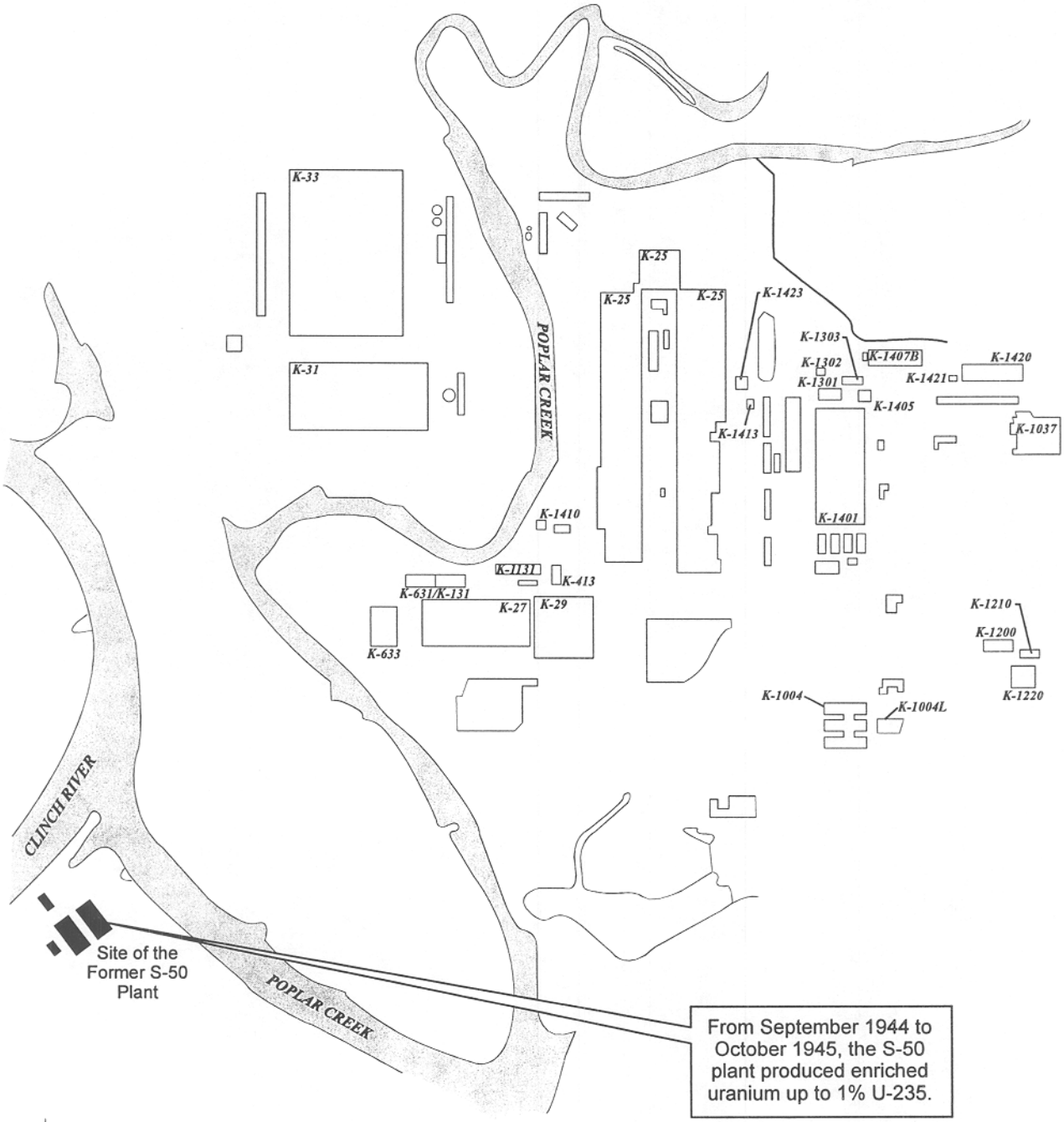

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FIGURE B-11

S-50 LIQUID THERMAL DIFFUSION PLANT

REFERENCES FOR APPENDIX B

ORGDP 1985. Oak Ridge Gaseous Diffusion Plant. Final Safety Analysis Report Oak Ridge Gaseous Diffusion Plant. K/D-5604. UNCI.

USDOE. 1979. United States Department of Energy. Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site. DOE/EA-0106.

APPENDIX C

MONITORED Y-12 AIRBORNE RELEASE POINTS

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Table C-1: Monitored Y-12 Airborne Release Points
(Dates of Sample Collection Varied by Monitoring Location)

Uranium Release Point[1]	Area or Operation(s) Exhausted	Mat'l Type[2]	Measured Exhaust Flow Rates[3]
11NF-01	C-1 Chip Burner, 12 Inch Stack (Enclosure), 9212	E	1,000 cfm (74)
11NF-02	C-1 Chip Burner, 5 Inch Process Exhaust, 9212	E	200 cfm (74)
11NF-03	C-Wing Stack Exhaust, 9212	E	13,000 cfm (71)
11NF-04	D-Wing Stack Exhaust, 9212	E	41,000 cfm (71)
11NF-14	West Headhouse Stack, 9212	E	28,000 cfm (71)
11NF-16	Reduction Area Exhaust, 9212	E	1,000 cfm (71)
11NF-18	Room 1010 Sintering Furnace Exhaust, 9212	E	1,000 cfm (71)
11NF-20	Room 1010 Furnace Room Exhaust, 9212	E	1,000 cfm (71)
11NF-21	Dry Chemistry Reactor Hood Exhaust, 9212	E	1,000 cfm (71)
11NF-22	C-1 PVC Stack, 9212	E	15,000 cfm[4] (71)
11NF-23	C-2 PVC Stack, 9212	E	15,000 cfm[4] (71)
11NF-25	B-1 Process Exhaust (Dissolver and Calciner), 9212	E	10,000 cfm (71)
11NF-28	B-1 Denitrator Room and Hood Exhaust, 9212	E	5,400 cfm (71)
11NF-29	B-1 2nd Floor Calciner and Dissolver, 9212	E	4,000 cfm (71)
11NF-34	B-1 Conversion Area Exhaust (Denitrator Rm.), 9212	E	10,000 cfm (71)
11NF-35	B-1 Feed Preparation Day Filter Exhaust, 9212	E	4,000 cfm (71)
11NF-38	Reduction Exhaust, Plenum Chamber, 9212	E	14,000 cfm (71)
11NF-50	Room 1022 E-Wing Lab Stack Exhaust, 9212	E	14,000 cfm (71)
11NF-51	Room 1021 (South) E-Wing Lab Stack Exhaust, 9212	E	15,000 cfm (71)
11NF-52	Room 1021 (West) E-Wing Lab Stack Exhaust, 9212	E	5,000 cfm (71)
11NF-53	Room 1021 (East) E-Wing Lab Stack Exhaust, 9212	E	5,000 cfm (71)
13JF-01	E-Wing Dust Collector Abs. Filter Exhaust, 9212	E	70,000 cfm (71)
13JF-03	E-Wing Recovery (Rms. 1008 and 1009), 9212	E	17,760 cfm (71)
13JF-37	E-Wing Machine Shop Exhaust, 9212	E	39,954 cfm (71)
17FF-05	O-Wing Mill and Room Exhaust, 9215	E	56,000 cfm (71)
20JF-11	M-Wing Exhaust Stack, 9215	E	44,000 cfm (71)
12PF-01	Bldg. 9768 Underground Exhaust, 9768 (Rms 20 & 27 9206)	E	38,800 cfm (71)

Uranium Release Point[1]	Area or Operation(s) Exhausted	Mat'l Type[2]	Measured Exhaust Flow Rates[3]
12PF-02	Room 25, Incinerator Exhaust, 9206	E	8,000 cfm
12PF-03	Rooms 24, 28 and 29 Exhaust (S-System), 9206	E	82,000 cfm
12PF-05	Room 19 Machining Hood Exhaust, 9206	E	8,100 cfm (88)
12PF-06	Rooms 20 and 22 Exhaust (Carbon Burner), 9206	E	11,000 cfm (71)
12PF-07	Room 30 Exhaust (L-System), 9206	E	78,000[5]cfm (71)
12PF-08	Room 20 Chip Handling Exhaust, 9206	E	
12PF-12	Room 30 Leaching Hood East, 9206	E	78,000[5] cfm (71)
12PF-13	Room 30 Leaching Hood West, 9206	E	78,000[5] cfm (71)
15EF-02	Dust Collector, 9998 (Later H-1 Foundry)	D	89,500 cfm (71)
27AF-01	Bag Filter House, 9201-5N	D	93,036 cfm (71)
13PF-12	E-Wing Dust Collector (Abs. Filter Exhaust-Bot), 9212	E	70,000[6] cfm (71)
13PF-13	E-Wing Dust Collector (Abs. Filter Exhaust-Top), 9212	E	70,000[6] cfm (71)
13PF-14	E-Wing Dust Collector (Bag Filter Exhaust-Center), 9212	E	70,000[6] cfm (71)
13PF-15	E-Wing Dust Collector (Bag Filter Exhaust-Bottom), 9212	E	70,000[6] cfm (71)
13PF-16	E-Wing Dust Collector (Bag Filter Exhaust-Top), 9212	E	70,000[6] cfm (71)
20KF-03	M-Wing Machine Hoods, 9215	E	44,000[7] cfm
20KF-04	M-Wing Machine Hoods, 9215	E	44,000[7] cfm
20KF-06	M-Wing Machine Hoods, 9215	E	44,000[7] cfm
12RF-09	Room 30, West Dock Exit, 9206	E	78,000[5] cfm (71)
12RF-10	Room 30 Fluid Bed, 9206	E	78,000[5] cfm (71)
12RF-11	Room 29 3rd Floor, 9206	E	

1 A set of location codes (e.g. 11NF-01) was initiated in 1964 for archiving stack data on computer disk. The first and second numbers represent the Division and Department, respectively. The first letter represents a specific operation (e.g., N=metal preparation), F designates a stack sample result, and the last two numbers (e.g., -01) represent a specific stack monitoring location.

2 Type of uranium exhausted, D = depleted, E = enriched.

3 Flow rates are within ± 10% of measured value determined in 1953, 1956, 1968, 1971, 1974, and 1988.

4 15,000 cfm is a combined volumetric flow rate for the process that fed two C-1 PVC Stacks, Building 9212.

5 78,000 cfm is a combined volumetric flow rate for Room 30's East and West Leaching hoods, and the L-system exhaust.

6 70,000 cfm is a combined volumetric flow rate for 6 separate E-Wing dust collector exhausts.

7 44,000 cfm is a combined volumetric flow rate for 3 separate M-Wing machine shop process exhausts.

Table C-2: Monitored Y-12 Waterborne Release Points (Dates of Sample Collection Varied by Monitoring Location)

Radioactive Material	Enrich-ment	Sampling Location[1]	Type Waste Stream	Type In-Plant Release Point	Final Release Point to Environment	Total Vol. Flow Rate (gal/day)
Uranium	Highly	9212 (L1)	Caustic Solutions	Storm Sewer(2)	East Fork Poplar Creek	43,000
Uranium	Highly	9212 (L2)	Condensate	Pipeline to Acid Ponds	Pond Sediment	446,000
Uranium	Highly	9728 (L3)	Glove Wash Solutions	Storm Sewer	East Fork Poplar Creek	29,000
Uranium	Highly	9212 (L4)	Misc. Solutions	Pipeline to Acid Ponds	Pond Sediment	500
Uranium	Highly	9212 (L5)	Raffinates	Pipeline to Acid Ponds	Pond Sediment	331,000
Uranium	Highly	9728 (L6)	Laundry Water	Storm Sewer	East Fork Poplar Creek	1,078,000
Uranium	Highly	Area 5 (L7)	Sanitary	Sanitary Sewer	East Fork Poplar Creek	NA
Uranium	Interm.	9206 (L9)	Raffinates and Condensates	Pipeline to Acid Ponds	Pond Sediment	48,600
Uranium	Depleted	9995 (L10)	Laboratory Solutions	Storm Sewer(2)	East Fork Poplar Creek	925
Uranium	Depleted	9998 (L11)	Spent Pickling Solution	Pipeline to Acid Ponds	Pond Sediment	2,800
Uranium	Depleted	9204-4 (L12)	Spent $FeCl^3$ Etch Solution	Trucked to Acid Pond	Pond Sediment	430
Uranium	Depleted	9204-4 (L13)	Spent Pickling Solution	Trucked to Acid Pond	Pond Sediment	1,450
Thorium	Normal	9201-5 (L14)	Spent Solution	Trucked to Acid Pond	Pond Sediment	7,200
Uranium	Highly	New Hope Pond (L30)	Mostly Cooling Water	Storm Sewers	East Fork Poplar Creek	$3.2x10^9$
Uranium	Depleted	New Hope Pond (L30)	Mostly Cooling Water	Storm Sewers	East Fork Poplar Creek	$3.2x10^9$
Uranium	Depleted	Acid Ponds (L31)	Percolation Ponds	Acid Disposal	Ground to Bear Creek	$9x10^{8(3)}$
Thorium	Normal	Acid Ponds (L31)	Percolation Ponds	Acid Disposal	Ground to Bear Creek	$9x10^{8(3)}$

1 Alternate release point designations followed by numerical location (e.g. L1) reported in Radioactive Effluent Monitoring and Control (UCC, 1971b).

2 Two monitoring stations (one in each of two storm sewers which serve Area 5) take continuous samples which are composited and analyzed weekly for radioactive materials.

3 Bear Creek flow at sample point

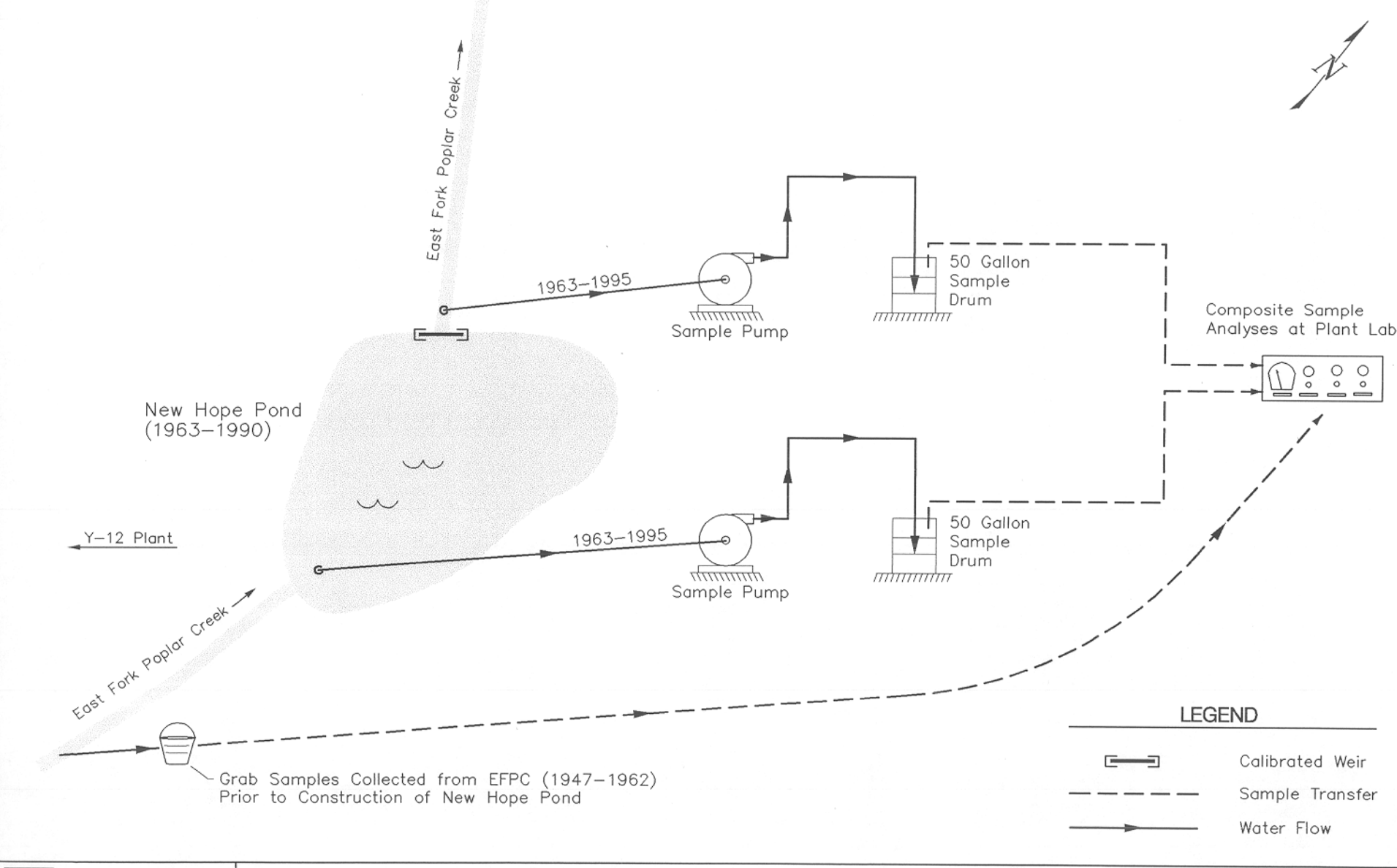

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FIGURE C-1

Continuous Proportional EFPC / New Hope Pond Sampler

APPENDIX D

AIR SOURCE TERM DEVELOPMENT AND RELEASE ESTIMATES FOR Y-12

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Appendix D contains a series of discussions and data presentations that document the approaches used by the Task 6 project team to estimate historical Y-12 air releases to the off-site environment. Descriptions of the Task 6 source term development is organized by different operating periods. The level of detail of the data and information used in the Task 6 analysis varies based on the availability of information for a particular operating period. The methods used by the project team to estimate releases were largely dictated by the quality and quantity of source term information that was identified during the Task 6 assessment. The sources of information available to the project team varied in nature from summary-level such as DOE reported releases to basic effluent monitoring data such as daily exhaust stack measurement data.

Using the information gathered during the Task 6 investigation, the project team reconstructed a more complete data set that was used to estimate past uranium releases. Although an uncertainty analysis of the Task 6 air source term was not within the scope of Task 6, experts interviewed during the project consider release estimates for enriched uranium to be suitable for the Task 6 screening assessment and are within an order of magnitude of actual releases.[1] However, it is noted that any future study of enriched uranium releases would benefit from a complete uncertainty analysis. Unlike enriched uranium, estimates for depleted uranium releases are not as well defined due to the larger amount of unmonitored and/or undocumented releases. However, Task 6 estimates include a large fraction of these releases and are considered to be a significant improvement over previously reported depleted uranium releases. It can be concluded from this analysis, that a formal statistical bounding of all uranium releases is warranted during any future study of ORR uranium.

This appendix is organized by Y-12 operating periods. The Task 6 project team calculated airborne release estimates for the following time periods:

- 1944 to 1956
- 1957, 1958, 1959, and 1963
- 1960, 1961, and 1962
- 1964 to 1988

DOE release estimates for 1989 through 1995 were used for the Task 6 analysis.

[1] Personal communications between Ed Owings, Charles West, and John Napier (former Y-12 workers) and the Task 6 project team.

D.1 SUMMARY OF TASK 6 ESTIMATES OF Y-12 URANIUM AIR RELEASES

Table D-1 contains a summary of uranium release estimates for Y-12 based on the Task 6 reconstruction of releases that occurred from 1944 to 1995. These estimates are based on both monitoring data, reported estimates, and approximations for operating periods and release sources that were largely unmonitored or undocumented. Effluent monitoring data and Task 6 release estimates for five separate operating periods are also presented in later sections of this appendix, and were used by the project team to compile Table D-1. Included in these sections are detailed spreadsheets of calculations and descriptions of the methods used by the project team to derive uranium release estimates. Table D-1 also includes previously reported DOE release estimates for 1944 to 1995.

The differences between the Task 6 and DOE release estimates are due to a more complete data and information set available to the project team. The DOE estimates were compiled over a relatively short time and did not include monitoring data and estimates of unmonitored releases that were identified during the Task 6 investigation.

Table D-1: Summary of Task 6 Estimates of Y-12 Uranium Air Releases

	Task 6 Uranium Release Estimates						DOE
YEAR	Uranium (kg)	Uranium (Ci)	U-234/235 (kg)	U-238 (kg)	U-234/235 (Ci)	U-238 (Ci)	Release Estimates (kg)
1944	311	0.35	5	307	0.24	0.11	55
1945	665	0.63	8	657	0.41	0.22	102
1946	385	0.44	6	379	0.31	0.13	102
1947	250	0.34	5	245	0.26	0.08	55
1948	650	0.39	3	647	0.17	0.22	0
1949	650	0.39	3	647	0.17	0.22	0
1950	650	0.39	3	647	0.17	0.22	0
1951	650	0.39	3	647	0.17	0.22	0
1952	650	0.39	3	647	0.17	0.22	0
1953	4015	2.04	12	4002	0.67	1.36	30
1954	3765	1.86	11	3754	0.58	1.28	32
1955	3765	1.87	11	3754	0.59	1.28	32
1956	3037	4.20	41	2995	3.20	1.00	43
1957	2309	6.60	72	2236	5.80	0.80	41
1958	5657	19.20	214	5443	17.40	1.80	41
1959	6149	13.90	148	6001	11.90	2.00	120
1960	934	2.73	28	906	2.43	0.31	99
1961	1321	4.33	45	1276	3.90	0.43	109
1962	1390	4.67	49	1341	4.21	0.46	100
1963	2091	2.83	28	2063	2.10	0.70	103
1964	2672	1.58	10	2662	0.68	0.91	170
1965	635	3.61	42	593	3.41	0.20	281
1966	921	1.40	14	907	1.09	0.31	212
1967	339	0.62	6	332	0.50	0.11	212
1968	439	0.37	3	436	0.22	0.15	211
1969	247	1.05	12	235	0.97	0.08	223
1970	295	1.68	19	276	1.59	0.09	259
1971	575	2.26	25	549	2.07	0.19	290
1972	874	3.95	47	827	3.66	0.28	222
1973	410	3.36	39	371	3.23	0.13	206
1974	208	0.35	4	204	0.28	0.07	207
1975	210	0.59	7	203	0.52	0.07	209
1976	208	0.40	4	204	0.33	0.07	207
1977	206	0.23	2	204	0.16	0.07	206
1978	206	0.24	2	204	0.17	0.07	205
1979	207	0.31	3	204	0.24	0.07	206
1980	222	0.54	6	216	0.47	0.07	218
1981	207	0.36	4	203	0.29	0.07	207
1982	207	0.55	6	201	0.48	0.07	207
1983	208	0.48	5	203	0.41	0.07	208
1984	331	0.46	5	326	0.35	0.11	329
1985	211	0.35	4	207	0.28	0.07	210
1986	213	0.42	5	208	0.35	0.07	211
1987	153	0.64	7	146	0.59	0.05	116
1988	145	0.35	4	142	0.30	0.05	116
1989	44	0.15	7	37	0.15	0.014	44
1990	21	0.80	6	15	0.08	0.007	21
1991	21	0.05	1	20	0.04	0.01	21
1992	7	0.04	1	7	0.04	0.006	7
1993	3	0.03	0.4	3	0.03	0.003	3
1994	24	0.04	0.4	24	0.03	0.002	24
1995	2	0.02	0.3	2	0.02	0.0021	2
Totals	49964	95	995	48967	78	17	6535

D.2 AIRBORNE RELEASE ESTIMATES FOR 1944 TO 1956

Release estimates for 1944 to 1956 were based on effluent monitoring data and reported releases for those release sources for which monitoring data was not available. This section describes the project team's application of both sources of information to derive cumulative releases for this operating period.

D.2.1 Effluent Monitoring Data

Effluent monitoring data presented in Y-12 documents were used by the project team to calculate releases and verify the accuracy of the reported releases for the period 1944 to 1956. These documents provide measured uranium concentrations in air (*e.g.*, $\mu g\ m^{-3}$) and exhaust air flow rates (*e.g.*, ft^3 $minute^{-1}$). These monitoring data represent releases for Buildings 9201-1, 9201-2, 9201-3, 9201-4, 9201-5, 9202, 9203, 9206, 9204-1, 9204-2, 9204-3, 9206 (Smith et al. 1945; Smith 1946; DallaValle 1945; DallaValle et al. 1945/1946). The project team calculated the number of kilograms of total uranium released by each release source per year by multiplying the measured uranium concentrations by the exhaust air flow rates. Kilograms released were then converted to the amount of alpha radioactivity released (curies y^{-1}, Ci y^{-1}) based on the estimated ^{235}U enrichment. The majority of releases 1944-1956 consisted mainly of:

natural uranium (0.0057 percent ^{234}U by weight ; 0.72 percent ^{235}U by weight; and 99.28 percent ^{238}U by weight), and

depleted uranium (an average of 0.002 percent ^{234}U by weight; 0.25 percent ^{235}U by weight; and 99.75 percent ^{238}U by weight was used).

The specific activities of the individual uranium isotopes used in the calculations are 6.29 Ci kg^{-1} for ^{234}U, 2.19×10^{-3} Ci kg^{-1} for ^{235}U and 3.4×10^{-4} Ci kg^{-1} for ^{238}U. Some of the releases that occurred during this operating period also contained enriched uranium, and for some years enriched uranium releases contributed significantly to the total activity released. The general formulas used to derive release estimates for 1944-1956 were:

Mass Release Rate (kg y^{-1}) = (g m^{-3}) (m^3 d^{-1}) (365d y^{-1}) (10^{-3}kg g^{-1}) and

Uranium Isotope Release Rate (Ci y^{-1}) = (kg y^{-1}) (percent weight of isotope) (Ci kg^{-1})[2].

Due to limited available monitoring data or release estimates for 1944, the project team estimated releases for this year based on an approximate 45 percent increase in production during 1945 and release estimates for 1945. Also, due to only limited available monitoring data and release estimates, the project team estimated 1956 releases based on an average of the preceding and subsequent years (*i.e.*, 1955 and 1957). Table D-2 presents a listing of the derived annual release estimates by building or process and the approximate uranium enrichment levels. This table presents uranium releases by total uranium mass and activity and mass and activity of individual uranium isotopes. Uranium mass is presented in kilograms and uranium activity is presented in curies.

[2]Percent weights of uranium isotopes (i.e., ^{234}U, ^{235}U, and ^{238}U) are based on reported enrichment level.

D.2.2 Reported Releases

Since a complete set of monitoring data for 1944 to 1956 was not available during the investigation, the project team used reported releases to complete the Task 6 release estimates for this time period (Griffith 1957). These additional data, which are presented in Griffith 1957, represent releases for Buildings 9206 (post 1947), 9211, 9212, and an unspecified beta building. According to the 1957 Griffith report, these release estimates were based on available effluent monitoring data, known releases, and production and inventory records. Documents that describe additional effluent monitoring data and production and inventory data used by Y-12 to derive their release estimates were not available for the Task 6 evaluation. Examples of these documents that may assist in ascertaining the uncertainty associated with reported estimates are presented in Section D.3.

The Griffith report provides the location of each release point, the amount of uranium released in terms of total kilograms, and the percent weight of ^{235}U contained in the airborne effluent. For example, 10,000 kilograms of depleted uranium were released from Building 9212 during the period 1953 through 1955. In this case, the project team assumed these releases occurred continuously over the three year period, and divided the 10,000 kg evenly for the three year release period. Based on the enrichment level for a given release, the project team then calculated the mass and activity for each uranium isotope from the total kilograms reported to have been released. These conversions were completed with the same approach used for the effluent monitoring data described Section D.2.1. Results for this analysis are included in Table D-2, along with the estimates derived from effluent monitoring data described in Section D.2.1.

D.2.3 References

DallaValle, J.M. 1945. Survey and Recommendations. August 1945. Report G-3.200.1. ChemRisk Repository No. 2418.

DallaValle, J.M. and Smith, S.B. 1945-1946. Reports - T Concentration (3 Reports). MS/ChR2-0048/DEL-REV. December 1945, April 1945, February 1946. ChemRisk Repository No. 2418.

Griffith, W.L. 1957. Uranium Losses from the Y-12 Plant to the Environment. Report Y-B92-13. 1957 (approximate year). (Deleted Revision) - Sanitized document from classified version. ChemRisk Repository No. 2416.

Smith, S.B. and McPherson, W.H. 1945. Pilot Scale Collection and Recovery of Air-Borne Tuballoy in Bldgs 9206, 9204-1, 92-4-2, and 9204-3. Report G-1.133.3. November 19, 1945. ChemRisk Repository No. 2999.

Smith, S.B. 1946. Miscellaneous Letter Reports for Uranium Air Concentrations. Box 11-7-4. February 24, 1946. ChemRisk Repository No. 2998.

Table D-2
Task 6 Air Release Estimates for 1944 to 1956

Year	Bldg	Total U (kg)	Total (Ci)	U-235 (kg)	U-238 (kg)	U-234 (Ci)	U-235 (Ci)	U-234/235 (Ci)	U-238 (Ci)	Percent U-235
1944	**9206**	23	0.0164	0.1656	22.8	0.0082	0.0004	0.0086	0.0078	nat.
	9202	115	0.0819	0.828	114.2	0.0412	0.0018	0.0430	0.0388	nat.
	9203	11	0.0078	0.0792	10.9	0.0039	0.0002	0.0041	0.0037	nat.
	9201-1,2,3	126	0.0897	0.9072	125.1	0.0452	0.0020	0.0472	0.0425	nat.
	9204-1	14	0.0100	0.1008	13.9	0.0050	0.0002	0.0052	0.0047	nat.
	9204-2	12	0.0085	0.0864	11.9	0.0043	0.0002	0.0045	0.0041	nat.
	Beta	10	0.1335	2.35	7.63	0.1258	0.0051	0.1309	0.0026	23.5%
	Total	311.0	0.3478	4.5172	306.5	0.2337	0.0099	0.2436	0.1042	
1945	**9206**	50	0.0356	0.36	49.6	0.0179	0.0008	0.0187	0.0169	nat.
	9202	255	0.1815	1.836	253.2	0.0914	0.0040	0.0954	0.0861	nat.
	9201-1,5	280	0.1993	2.016	278.0	0.1004	0.0044	0.1048	0.0945	nat.
	9204-1	14	0.0100	0.1008	13.9	0.0050	0.0002	0.0052	0.0047	nat.
	9204-2	48	0.0342	0.3456	47.7	0.0172	0.0008	0.0180	0.0162	nat.
	9204-3	7	0.0050	0.0504	6.9	0.0025	0.0001	0.0026	0.0024	nat.
	Beta	10	0.1335	2.35	7.63	0.1258	0.0051	0.1309	0.0026	23.5%
	NA	0.5	0.0388	0.4675	0.0265	0.0377	0.0010	0.0388	0.0000	93.5%
	Total	664.5	0.6379	7.5263	656.9	0.3980	0.0165	0.4145	0.2234	
1946	**9206**	50	0.0356	0.4	49.6	0.0179	0.0008	0.0187	0.0169	nat.
	9202	255	0.1815	1.8	253.2	0.0914	0.0040	0.0954	0.0861	nat.
	9204-1	14	0.0100	0.1008	13.9	0.0050	0.0002	0.0052	0.0047	nat.
	9204-2	48.3	0.0344	0.34776	48.0	0.0173	0.0008	0.0181	0.0163	nat.
	9204-3	7.2	0.0086	0.144	7.1	0.0059	0.0003	0.0062	0.0024	2%
	Beta	10	0.1335	2.35	7.63	0.1258	0.0051	0.1309	0.0026	23.5%
	NA	0.5	0.0388	0.4675	0.0265	0.0377	0.0010	0.0388	0.0000	93.5%
	Total	385.0	0.4424	5.6	379.4	0.3011	0.0123	0.3134	0.1290	
1947	**9206**	50	0.0356	0.36	49.6	0.0179	0.0008	0.0187	0.0169	nat.
	9202	127	0.0904	0.9144	126.1	0.0455	0.0020	0.0475	0.0429	nat
	9204-2	48.3	0.0344	0.34776	48.0	0.0173	0.0008	0.0181	0.0163	nat.
	9204-3,4	14	0.0103	0.280	13.7	0.0050	0.0006	0.0056	0.0047	nat
	Beta	10	0.1335	2.35	7.63	0.1258	0.0051	0.1309	0.0026	23.5%
	NA	0.5	0.0388	0.4675	0.0265	0.0377	0.0010	0.0388	0.0000	93.5%
	Total	249.8	0.3430	4.7	245.1	0.2493	0.0103	0.2597	0.0833	
1948	**9206**	400	0.1882	1.0	399	0.050	0.00219	0.053	0.13566	0.25%
	9212	250	0.1780	1.8	248.2	0.0896	0.0039	0.0936	0.0844	nat.
	9212	0.28	0.0217	0.3	0.015	0.0211	0.0006	0.0217	0.0000	93.5%
	Total	650.3	0.3878	3.1	647.2	0.1611	0.0067	0.1678	0.2201	
1949	**9206**	400	0.1882	1.0	399	0.050	0.00219	0.053	0.13566	0.25%
	9212	250	0.1780	1.8	248.2	0.0896	0.0039	0.0936	0.0844	nat.
	9212	0.28	0.0217	0.3	0.015	0.0211	0.0006	0.0217	0.0000	93.5%
	Total	650.3	0.3878	3.1	647.2	0.1611	0.0067	0.1678	0.2201	
1950	**9206**	400	0.1882	1.0	399	0.050	0.00219	0.053	0.13566	0.25%
	9212	250	0.1780	1.8	248.2	0.0896	0.0039	0.0936	0.0844	nat.
	9212	0.28	0.0217	0.3	0.015	0.0211	0.0006	0.0217	0.0000	93.5%
	Total	650.3	0.3878	3.1	647.2	0.1611	0.0067	0.1678	0.2201	

Table D-2
Task 6 Air Release Estimates for 1944 to 1956

Year	Bldg	Total U (kg)	Total (Ci)	U-235 (kg)	U-238 (kg)	U-234 (Ci)	U-235 (Ci)	U-234/235 (Ci)	U-238 (Ci)	Percent U-235
1951	**9206**	400	0.1882	1.0	399	0.050	0.00219	0.053	0.13566	0.25%
	9212	250	0.1780	1.8	248.2	0.0896	0.0039	0.0936	0.0844	nat.
	9212	0.28	0.0217	0.3	0.015	0.0211	0.0006	0.0217	0.0000	93.5%
	Total	650.3	0.3878	3.1	647.2	0.1611	0.0067	0.1678	0.2201	
1952	**9206**	400	0.1882	1.0	399	0.050	0.00219	0.053	0.13566	0.25%
	9212	250	0.1780	1.8	248.2	0.0896	0.0039	0.0936	0.0844	nat.
	9212	0.28	0.0217	0.3	0.015	0.0211	0.0006	0.0217	0.0000	93.5%
	Total	650.3	0.3878	3.1	647.2	0.1611	0.0067	0.1678	0.2201	
1953	**9206**	400	0.1882	1.0	399	0.050	0.00219	0.053	0.13566	0.25%
	9212	3330	1.5665	8.3	3321.7	0.419	0.0182	0.437	1.129	0.25%
	9212	250	0.1780	1.8	248.2	0.0896	0.0039	0.0936	0.0844	nat.
	9212	0.8	0.0620	0.7	0.042	0.0604	0.0016	0.0620	0.0000	93.5%
	9206	1.3	0.0174	0.325	0.975	0.016354	0.0007	0.0171	0.0003	25%
	9211	32.5	0.0231	0.234	32.3	0.0117	0.0005	0.0122	0.0110	nat.
	Total	4014.6	2.0352	12.4	4002.2	0.6473	0.0272	0.6745	1.3607	
1954	**9206**	400	0.1882	1.0	399	0.050	0.0022	0.053	0.136	0.25%
	9212	3330	1.5665	8.3	3321.7	0.419	0.0182	0.437	1.129	0.25%
	9212	0.8	0.0620	0.7	0.042	0.0604	0.0016	0.0620	0.0000	93.5%
	9206	1.3	0.0174	0.325	0.975	0.0164	0.0007	0.0171	0.0003	25%
	9211	32.5	0.0231	0.234	32.3	0.0117	0.0005	0.0122	0.011	nat.
	Total	3764.6	1.8573	10.6	3754.0	0.5576	0.0233	0.5809	1.2763	
1955	**NA**	0.6	0.0082	0.225	0.375	0.0075	0.0005	0.0080	0.0001	37.5%
	9206	400	0.1882	1.0	399	0.050	0.0022	0.053	0.1357	0.25%
	9212	3330	1.5665	8.3	3321.7	0.419	0.0182	0.437	1.1294	0.25%
	9212	0.8	0.0620	0.7	0.042	0.0604	0.0016	0.0620	0.0000	93.5%
	9206	1.3	0.0174	0.325	0.975	0.0164	0.0007	0.0171	0.0003	25%
	9211	32.5	0.0231	0.234	32.3	0.0117	0.0005	0.0122	0.0110	nat.
	Total	3765.2	1.8654	10.9	3754.3	0.5652	0.0238	0.5889	1.2765	
1956	**NA**	2	0.0272	0.75	1.25	0.0252	0.0016	0.0268	0.0004	37.5%
	9212	36.5	0.0172	0.1	36.4	0.005	0.0002	0.005	0.0124	0.25%
	9212	0.8	0.0620	0.7	0.042	0.0604	0.0016	0.0620	0.0000	93.5%
	9206	1.3	0.0174	0.325	0.975	0.0164	0.0007	0.0171	0.0003	25%
	9211	32.5	0.0231	0.234	32.3	0.0117	0.0005	0.0122	0.0110	nat.
	Total	73.1	0.1470	2.1	70.9	0.1181	0.0047	0.1228	0.0241	
1956-R1	**Adj. Total ***	3037.1	4.2327	41.4	2995	3.1	0.09	3.2	1.0	

* 1956 was adjusted based on an average of 1955 and 1957 estimates. Adjustment was made due to limited release data for 1956, and makes the estimate consistent with production increases for that year.

D.3 SAMPLES OF TENNESSEE EASTMAN REPORTS FOR 1943 TO 1947 (EFFLUENT MONITORING/URANIUM RELEASE DATA)

Table D-3 contains a list of potentially relevant reports for Task 6 that were identified by title through a search of the Manhattan Engineering District (MED) bibliography list located at the Y-12 Central Files repository. Unfortunately, copies of the majority of these reports were not located during the Task 6 study. These would likely be of interest in any further study of uranium releases from Y-12.

TABLE D-3: Samples of Tennessee Eastman Reports for 1943 to 1947 Potentially Containing Effluent Monitoring/Uranium Release Data (Majority of reports identified were not located during the Task 6 Investigation)

Y-12 Document Number	Document Title	Date	Author
B-2.175.3A	Monitoring Reports for Two Weeks Period Ending 11-2-45	11-9-45	A.C. Schmidt
B-2.175.4A	Air-borne T Source Data Sheets	12-21-45	A.C. Schmidt
B-2.175.5A	Air-borne T Source Data Sheets	12-21-45	A.C. Schmidt
B-2.175.6A	Report of work done on the control of air-borne losses during the month of December, 1945	1-11-46	A.C. Schmidt
B-2.175.9A	Report of work on the control of air-borne losses during the two week period ending 1-26-45	1-29-45	A.C. Schmidt
B-2.175.10A	Air-borne T Source Data Sheet for the R.O. and batching equipment in rooms 40, 41 and 42, Bldg. 9206A	2-5-45	A.C. Schmidt
B-2.175.11A through 28A	Air-borne T Source Data Sheet	2-8-45	A.C. Schmidt
B-2.175.29A	Report of work on the control of air-borne losses during the interval from Jan. 26 to Feb. 16, 1946	2-18-45	A.C. Schmidt
B-2.175.30A	"Air-borne T source data sheets" for the carbon burning room on the second floor of Bldg. 9211	3-15-46	A.C. Schmidt
C-5.381.1	Amount of T Discharged from a Centrifuge Seep Bowl upon Stopping	7-18-45	C.C. Haws, G.H. Clewett
C-5.381.15-16	Alpha Count Analysis of Balance Washings	2-8/13-46	R.H. Atkinson, G.H. Clewett
C-5.381.22	Alpha Count Analysis of Balance Washings	3-5-46	R.H. Atkinson, G.H. Clewett
ID-701-800	Production Reports for Department 180	1944	A. Bell
ID-801-900	Reports on Run Summary, Recovery Data, Charge Inventory, Standard Charge Locations and M Washing Summary	1944	K.C. Peterson
ID-901-1000	Reports on Run Summary, Recovery Data, Charge Inventory, Standard Charge Locations and M Washing Summary	1944	K.C. Peterson
CD-1001	Special Experiments - 9204-1	8-10-44	J.W. Morfitt
CD-1002	Material Balance Sheets	8-14-44	K.C. Peterson
CD-1003	M Washing Summary	8-14-44	K.C. Peterson
CD-1016	Losses of 720 (normal uranium) in Process Waters	12-1-44	J.W. Morfitt
CD-1026	Report on Spills Involving EPA-I	12-29-44	M.L. Piker
CD-1059	Air Contamination in 9204 Beta Bldgs.	5-17-45	H. Winkler
CD-1073	Summary of Current Charge Losses	8-15-45	M.L. Piker, J.W. Morfitt

D.4 AIRBORNE RELEASE ESTIMATES FOR 1957

Exhaust stack sampling data reported in monthly Y-12 health physics reports for a limited number of exhaust stacks were used by the project team to estimate enriched and depleted uranium releases for 1957. Daily average net alpha radioactivity concentrations reported in units of disintegrations per minute per cubic meter (d m^{-1} m^{-3}) are presented in these Y-12 documents. However, due to the limited amount of monitoring data for this period, the project team used the maximum reported average concentration for each stack to estimate total releases. Monthly averages are based on daily measurements of uranium concentrations in stack effluents. The maximum average concentration for each stack was multiplied by the air exhaust flow rate, in cubic meters per year (m^3 y^{-1}) for each stack to yield the total activity released per year for each stack (d min^{-1} y^{-1}). The total d min^{-1} per year for all stacks were then summed to yield the total d min^{-1} released from Y-12 per year. To convert the d min^{-1} per year released to activity (curies), the annual d min^{-1} were divided by 2.22 x10^{12} d min^{-1} per curie. The total curies were then multiplied by a factor of 4 to correct for sample line losses and by a factor of 3 to correct for alpha burial losses. Total activity was then separated into activity per uranium isotope (*i.e.*, ^{234}U, ^{235}U, and ^{238}U) based on the enrichment level. For 93.5 percent ^{235}U by weight enrichment, an average of 97.4 percent of the total activity is associated with ^{234}U; 2.6 percent is from ^{235}U; and 0.02 percent is from ^{238}U. For depleted uranium, an average of 26.8 percent of the total activity is associated with ^{234}U, 1.2 percent is from ^{235}U, and 72 percent is from ^{238}U. Total kilograms of each uranium isotope released were then calculated by dividing the activity of each isotope by the following specific activities: 6.29 Ci kg^{-1} for ^{234}U, 2.19×10^{3} Ci kg^{-1} for ^{235}U and 3.4×10^{-4} Ci kg^{-1} for ^{238}U. Table D-4 presents the stack monitoring data and release estimates for 1957 based on the Task 6 calculations.

D.4.1 References

McLendon, J.D. 1957. Health Physics Reports - Bldgs. 9206 and 9211. MS/ChR2-0011/DEL REV. ChemRisk Repository No. 3105.

Table D-4: Task 6 1957 Air Release Estimates

Building	Date of Collection	Area Description*	Time of Day	Sample Results			
				Sample Number	Avg U-Air Conc d/min/m³		
9212	02/1957	C-Wing cast iron stack	AM	14	30		
9212	02/1957	C-Wing cast iron stack	PM	3	47		
9212	03/1957	C-Wing cast iron stack	AM	19	22		
9212	03/1957	C-Wing cast iron stack	PM	16	19		
9212	04/1957	C-Wing cast iron stack	AM	18	29		
9212	04/1957	C-Wing cast iron stack	PM	15	9		
9212	05/1957	C-Wing cast iron stack	AM	24	50		
9212	05/1957	C-Wing cast iron stack	PM	17	77		
9212	06/1957	C-Wing cast iron stack	PM	15	16		
9212	06/1957	C-Wing cast iron stack	AM	20	20		
9212	07/1957	C-Wing cast iron stack	AM	24	67		
9212	07/1957	C-Wing cast iron stack	PM	18	42		
9212	08/1957	C-Wing cast iron stack	AM	20	259		
9212	08/1957	C-Wing cast iron stack	PM	16	12		
9212	08/1957	Dry chemistry exhaust duct	AM	18	285		
9212	09/1957	C-Wing cast iron stack	AM	19	39		
9212	09/1957	C-Wing cast iron stack	PM	14	30		
9212	09/1957	Dry chemistry exhaust duct	AM	19	40		
9212	09/1957	Dry chemistry exhaust duct	PM	4	58		
9212	10/1957	C-Wing cast iron stack	AM	23	24		
9212	10/1957	C-Wing cast iron stack	PM	16	38		
9212	10/1957	Dry chemistry exhaust duct	AM	25	95		
9212	10/1957	Dry chemistry exhaust duct	PM	20	184		
9212	11/1957	C-Wing cast iron stack	AM	16	33		
9212	11/1957	C-Wing cast iron stack	PM	4	9		
9212	11/1957	Dry chemistry exhaust duct	AM	19	21		
9212	11/1957	Dry chemistry exhaust duct	PM	14	2	m^3/yr	dpm/yr
					285	**8.32E+08**	**2.37E+11**

* C-Wing cast iron stack and Dry chemistry exhaust duct were the two names used for the same stack

Table D-4: Task 6 1957 Air Release Estimates

Building	Date of Collection	Area Description*	Time of Day	Sample Results			
				Sample Number	Avg U-Air Conc d/min/m³		
9212	02/1957	D-Wing cast iron stack	AM	14	56		
9212	02/1957	D-Wing cast iron stack	PM	3	13		
9212	03/1957	D-Wing cast iron stack	AM	19	107		
9212	03/1957	D-Wing cast iron stack	PM	16	247		
9212	04/1957	D-Wing cast iron stack	AM	18	321		
9212	04/1957	D-Wing cast iron stack	PM	15	504		
9212	05/1957	D-Wing cast iron stack	AM	24	111		
9212	05/1957	D-Wing cast iron stack	PM	18	103		
9212	06/1957	D-Wing cast iron stack	PM	15	246		
9212	06/1957	D-Wing cast iron stack	AM	20	137		
9212	06/1957	D-Wing cast iron stack	AM	20	137		
9212	07/1957	D-Wing cast iron stack	AM	24	527		
9212	07/1957	D-Wing cast iron stack	PM	18	183		
9212	08/1957	D-Wing cast iron stack	AM	20	165		
9212	08/1957	D-Wing cast iron stack	PM	16	64		
9212	09/1957	D-Wing cast iron stack	AM	19	277		
9212	09/1957	D-Wing cast iron stack	PM	15	479		
9212	10/1957	D-Wing cast iron stack	AM	24	248		
9212	10/1957	D-Wing cast iron stack	PM	20	293		
9212	11/1957	D-Wing cast iron stack	AM	17	221		
9212	11/1957	D-Wing cast iron stack	PM	10	281	m^3/yr	dpm/yr
					527	**6.27E+08**	**3.31E+11**
9212	01/1957	E-Wing exhaust stack	AM	20	19		
9212	01/1957	E-Wing exhaust stack	PM	16	4		
9212	02/1957	E-Wing exhaust stack	AM	20	28		
9212	02/1957	E-Wing exhaust stack	PM	16	5		
9212	03/1957	E-Wing exhaust stack	AM	20	15		
9212	03/1957	E-Wing exhaust stack	PM	16	8		
9212	04/1957	E-Wing exhaust stack	AM	18	13		
9212	04/1957	E-Wing exhaust stack	PM	15	6		
9212	05/1957	E-Wing exhaust stack	AM	24	16		
9212	05/1957	E-Wing exhaust stack	PM	18	12		
9212	06/1957	E-Wing exhaust stack	PM	15	32		
9212	06/1957	E-Wing exhaust stack	AM	19	73		
9212	06/1957	E-Wing exhaust stack	AM	19	73		
9212	07/1957	E-Wing exhaust stack	AM	24	77		
9212	07/1957	E-Wing exhaust stack	PM	18	22		
9212	08/1957	E-Wing exhaust stack	AM	20	69		
9212	08/1957	E-Wing exhaust stack	PM	15	34		
9212	09/1957	E-Wing exhaust stack	AM	19	125		
9212	09/1957	E-Wing exhaust stack	PM	15	88		
9212	10/1957	E-Wing exhaust stack	AM	25	95		
9212	10/1957	E-Wing exhaust stack	PM	20	12		
9212	11/1957	E-Wing exhaust stack	AM	18	59		
9212	11/1957	E-Wing exhaust stack	PM	13	15	m^3/yr	dpm/yr
					125	**9.13E+08**	**1.14E+11**

Table D-4: Task 6 1957 Air Release Estimates

Building	Date of Collection	Area Description*	Time of Day	Sample Results			
				Sample Number	Avg U-Air Conc d/min/m³		
9212	08/1957	Head house exhaust duct	AM	18	115		
9212	08/1957	UO2 production exhaust duc	AM	18	465		
9212	09/1957	Head house exhaust duct	AM	18	612		
9212	09/1957	Head house exhaust duct	PM	4	9		
9212	09/1957	UO2 production exhaust duc	AM	19	51		
9212	09/1957	UO2 production exhaust duc	PM	4	77		
9212	10/1957	Head house exhaust duct	AM	25	217		
9212	10/1957	Head house exhaust duct	PM	19	329		
9212	10/1957	UO2 production exhaust duc	AM	25	17		
9212	10/1957	UO2 production exhaust duc	PM	20	52		
9212	11/1957	Head house exhaust duct	AM	16	353		
9212	11/1957	Head house exhaust duct	PM	14	177		
9212	11/1957	UO2 production exhaust duc	AM	19	7		
9212	11/1957	UO2 production exhaust duc	PM	14	14	m^3/yr	dpm/yr
					612	**5.74E+08**	**3.51E+11**

* Head house exhaust duct and UO2 production exhaust duct were the two nanes used for the same stack

Total Activity for 1957	dpm/yr	alpha (Ci/yr)	
	1.03E+12	5.58	*
93.5% Enriched	Ci	kg	
U-234	5.43	0.86	
U-235	0.145	66.3	
U-238	0.00112	3.3	
TOTAL (kg)		2239	
Unmonitored Depleted (0.25%)	Ci	kg	
U-234	0.28	0.04	
U-235	0.0123	6	
U-238	0.76	2233	
Total Uranium Released in 1957	Ci	kg	
U-234	5.7	0.9	
U-235	0.157	71.9	
U-238	0.76	2236	
TOTAL	6.63	2309	

* Adjusted by a factor of 4 for sample line losses and a factor of 3 for alpha burial losses.

D.5 AIRBORNE RELEASE ESTIMATES FOR 1958, 1959, and 1963

Quarterly stack sampling results presented in Y-12 laboratory reports for 1958, 1959, and 1963 were used by the project team to derive enriched and depleted uranium release estimates for these three years (Tucker et al. 1995). Quarterly average net alpha disintegrations per minute per cubic meter (d min^{-1} m^{-3}) for each stack are reported for each monitoring period. Samples were collected in exhaust stacks down stream of exhaust filters in Buildings 9206, 9212, 9215, and 9998. 1958 and 1959 are the first years for which the project team was able to find nearly complete sets of monitoring data. Depleted uranium stack monitoring data were not available for the fourth quarter 1959, and only fourth quarter enriched and depleted monitoring data were available for 1963. Due to limited production and monitoring data for 1963 available to the project team, estimates of uranium releases for the first 3 quarters were not included in the total releases. Estimates of undocumented depleted uranium releases for the fourth quarter 1959 were also not included in the total releases. It is noted that release estimates for 1960 through 1962 are presented separately in Section D.6 of this appendix due to differences in data content and format presented in other Y-12 documents.

For 1958, 1959, and 1963, the quarterly average net alpha concentration (d min^{-1} m^{-3}) and quarterly flow rate (m^{-3} qtr^{-1}) for each stack were multiplied together and then converted to curies released per quarter. Total curies per stack were then summed to arrive at the total curies released per year for either enriched or depleted exhaust stacks. Separate totals were derived for enriched and depleted stacks. Total curies per year were then multiplied by a factor of 4 to correct for sample line losses. Y-12 laboratory workers had previously corrected for burial losses and, therefore, it was not necessary to include this step in the Task 6 assessment. Total activity was then separated into activity per uranium isotope (*i.e.*, ^{234}U, ^{235}U, and ^{238}U) based on the enrichment level. For 93.5 percent ^{235}U by weight enrichment, an average of 97.4 percent of the total activity is associated with ^{234}U; 2.6 percent from ^{235}U; and 0.02 percent from ^{238}U. For depleted uranium, an average of 26.8 percent of the total activity is associated with ^{234}U, 1.2 percent is from ^{235}U, and 72 percent is from ^{238}U. Once the activities of the individual uranium isotopes were determined, the project team converted these to kilograms released for each isotope by using the following specific activities: 6.29 Ci kg^{-1} for ^{234}U, 2.19×10^{-3} Ci kg^{-1} for ^{235}U and 3.4×10^{-4} Ci kg^{-1} for ^{238}U. Results of the Task 6 analysis for 1958, 1959, and 1963 are presented in Tables D-5, D-6, and D-7.

D.5.1 References

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Table D-5
Task 6 1958 Release Estimates

93.5% Enriched Uranium

period	stack/area	avg. dpm/m^3	flow rate (m^3/qtr)	dpm/qtr	Ci/qtr.
1st Q 1958	282-04	1567	1.49E+08	2.33E+11	1.05E-01
	282-03	412	4.72E+07	1.94E+10	8.76E-03
	282-1,2,11,12,13	2335	2.54E+08	5.93E+11	2.67E-01
	572 (all)	527	1.60E+08	8.42E+10	3.79E-02
	573 (all)	71	2.03E+08	1.44E+10	6.50E-03
	624 (all)	246	2.98E+08	7.32E+10	3.30E-02
2nd Q 1958	282-1,2,17,15	1651	2.54E+08	4.20E+11	1.89E-01
	282-16,18	1453	3.63E+06	5.27E+09	2.38E-03
	282-03	555	4.72E+07	2.62E+10	1.18E-02
	282-04	973	1.49E+08	1.45E+11	6.52E-02
	282-14	3232	1.02E+08	3.29E+11	1.48E-01
	572 (all)	526	1.60E+08	8.40E+10	3.78E-02
	573-1,2,3,4,5,6	49	2.03E+08	9.96E+09	4.49E-03
	624 (all)	628	2.98E+08	1.87E+11	8.42E-02
3rd Q 1958	282-1,2,17,19	775	2.54E+08	1.97E+11	8.87E-02
	282-16,18	392	3.63E+06	1.42E+09	6.41E-04
	282-03	289	4.72E+07	1.36E+10	6.14E-03
	282-04	349	1.49E+08	5.19E+10	2.34E-02
	282-14	3158	1.02E+08	3.21E+11	1.45E-01
	572 (all)	14823	1.60E+08	2.37E+12	1.07E+00
	624-01	3360	1.42E+08	4.76E+11	2.14E-01
	624-03	1072	1.09E+07	1.17E+10	5.26E-03
	624-2,5,6 7,8	866	2.98E+08	2.58E+11	1.16E-01
	624-04	343	3.99E+07	1.37E+10	6.17E-03
	573 (all)	77	2.03E+08	1.57E+10	7.05E-03
4th Q 1958	282-1,17,19	4985	2.54E+08	1.27E+12	5.71E-01
	282-03	824	4.72E+07	3.89E+10	1.75E-02
	282-04	459	1.49E+08	6.83E+10	3.08E-02
	282-14	3455	1.02E+08	3.51E+11	1.58E-01
	282-16,18	530	3.63E+06	1.92E+09	8.67E-04
	282-20	145	5.08E+07	7.37E+09	3.32E-03
	572(all)	8641	1.60E+08	1.38E+12	6.22E-01
	573 (all)	112	2.03E+08	2.28E+10	1.03E-02
	624-2,5,6,7,8	467	2.98E+08	1.39E+11	6.26E-02
	624-01	86	1.42E+08	1.22E+10	5.48E-03
	624-03	338	1.09E+07	3.68E+09	1.66E-03
	624-04	65	3.99E+07	2.60E+09	1.17E-03

Depleted Uranium

period	stack/area	avg. dpm/m^3	flow rate (m^3/qtr)	dpm/qtr	Ci/qtr
1st Q 1958	281(all)	2005	4.07E+08	8.15E+11	3.67E-01
2nd Q 1958	281(all)	708	4.07E+08	2.88E+11	1.30E-01
3rd Q 1958	281 (all)	343	4.07E+08	1.39E+11	6.28E-02
4th Q 1958	281(all)	446	4.07E+08	1.81E+11	8.17E-02

1958 Release Totals for 93.5% Enriched Uranium (Ci) **16.66** *

Releases by Isotope	U-234	U-235	U-238
Ci	16.21	0.43	0.0033
kg	2.58	197.77	9.80

1958 Release Totals for Depleted Uranium (Ci) **2.57** *

Releases by Isotope	U-234	U-235	U-238
Ci	0.68	0.03	1.85
kg	0.11	13.59	5432.90

Total Uranium Release Estimates for 1958 (93.5% Enriched + Depleted)

Releases by Isotope	U-234	U-235	U-234/235	U-238	Total
Ci	16.89	0.46	17.36	1.85	19.21
kg	2.69	211.36	214.04	5442.70	5656.74

* Adjusted by a factor of 4 for sample line losses

Table D-6
Task 6 1959 Release Estimates

93.5% Enriched Uranium

period	stack/area	avg. dpm/m^3	flow rate (m^3/qtr)	dpm/qtr	Ci/qtr.
1st Q 1959	282-04	2824	1.49E+08	4.20E+11	1.89E-01
	282-03	1081	4.72E+07	5.10E+10	2.30E-02
	282-1,2,17,19	2249	2.54E+08	5.72E+11	2.57E-01
	282-14	2089	1.02E+08	2.12E+11	9.56E-02
	282-16,18	588	3.63E+06	2.13E+09	9.62E-04
	282-20	57	5.08E+07	2.90E+09	1.30E-03
	282-21	997	5.45E+07	5.43E+10	2.45E-02
	572 (all)	5705	1.60E+08	9.11E+11	4.10E-01
	573 (all)	304	2.03E+08	6.18E+10	2.78E-02
	624-3	250	1.09E+07	2.72E+09	1.23E-03
	624-4	20	3.99E+07	7.99E+08	3.60E-04
	624-1,2,5,6,7,8	525	2.98E+08	1.56E+11	7.04E-02
2nd Q 1959	282-2,17,19	228	2.54E+08	5.79E+10	2.61E-02
	282-16,18	157	3.63E+06	5.70E+08	2.57E-04
	282-03	532	4.72E+07	2.51E+10	1.13E-02
	282-04	163	1.49E+08	2.43E+10	1.09E-02
	282-14	881	1.02E+08	8.96E+10	4.03E-02
	282-20	90	5.08E+07	4.57E+09	2.06E-03
	282-21,23	366	5.45E+07	1.99E+10	8.98E-03
	572 (all)	5581	1.60E+08	8.91E+11	4.02E-01
	573-1,2,3,4	183	2.03E+08	3.72E+10	1.68E-02
	624-3	417	1.09E+07	4.54E+09	2.05E-03
	624-4	45	3.99E+07	1.80E+09	8.09E-04
	624-1,2,5,6,7,8	565	2.98E+08	1.68E+11	7.58E-02
3rd Q 1959	282-1,17,19	2168	2.54E+08	5.51E+11	2.48E-01
	282-16,18	148	3.63E+06	5.37E+08	2.42E-04
	282-03	70	4.72E+07	3.30E+09	1.49E-03
	282-04	308	1.49E+08	4.58E+10	2.06E-02
	282-14	823	1.02E+08	8.37E+10	3.77E-02
	282-20	27	5.08E+07	1.37E+09	6.18E-04
	282-21,23	205	5.45E+07	1.12E+10	5.03E-03
	572 (all)	5195	1.60E+08	8.30E+11	3.74E-01
	573 (all)	288	2.03E+08	5.85E+10	2.64E-02
	624-03	334	1.09E+07	3.64E+09	1.64E-03
	624-1,2,5,6 7,8	120	2.98E+08	3.57E+10	1.61E-02
	624-04	7	3.99E+07	2.80E+08	1.26E-04
4th Q 1959	572 (all)	10703	1.68E+08	1.79E+12	8.10E-01

1959 Release Totals for 93.5% Enriched Uranium (Ci) **11.09** *

Releases by Isotope	U-234	U-235	U-238
Ci	10.79	0.29	0.0022
kg	1.71	131.61	6.52

Depleted Uranium

period	stack/area	avg. dpm/m^3	flow rate (m^3/qtr)	dpm/qtr	Ci/qtr
1st Q 1959	281(all)	319	4.07E+08	1.30E+11	5.84E-02
2nd Q 1959	281(all)	3202	4.07E+08	1.30E+12	5.86E-01
3rd Q 1959	281 (all)	343	4.07E+08	1.39E+11	6.28E-02
4th Q 1959	*Monitoring Data Not Available*				

1959 Release Totals for Depleted Uranium (Ci) **2.83** *

Releases by Isotope	U-234	U-235	U-238
Ci	0.76	0.03	2.04
kg	0.12	14.99	5994.49

Total Uranium Release Estimates for 1959 (93.5% Enriched + Depleted)

Releases by Isotope	U-234	U-235	U-234/235	U-238	Total
Ci	11.54	0.32	11.86	2.04	13.90
kg	1.84	146.61	148.44	6001.01	6149.46

* Adjusted by a factor of 4 for sample line losses

Table D-7
Task 6 1963 Release Estimates

93.5% Enriched Uranium

period	stack/area	avg. dpm/m^3	flow rate (m^3/qtr)	dpm/qtr	Ci/qtr.
1st - 3rd Q 1963	*Monitoring Data Not Available*				
4th Q 1963	282-04	56	1.49E+08	8.34E+09	3.75E-03
	282-03	1081	4.72E+07	5.10E+10	2.30E-02
	282-1,2,17,19	213	2.54E+08	5.41E+10	2.44E-02
	282-14	34	1.02E+08	3.46E+09	1.56E-03
	282-16,18	129	3.63E+06	4.68E+08	2.11E-04
	282-20,23,25,27,29, 30-37	822	5.08E+07	4.18E+10	1.88E-02
	282-21	997	5.45E+07	5.43E+10	2.45E-02
	572 (all)	566	1.60E+08	9.04E+10	4.07E-02
	573 (all)	57	2.03E+08	1.16E+10	5.22E-03
	624-3	104	1.09E+07	1.13E+09	5.10E-04
	624-4	687	3.99E+07	2.74E+10	1.24E-02
	624-1,2,5,6,7,8	2308	2.98E+08	6.87E+11	3.09E-01

Depleted Uranium

period	stack/area	avg. dpm/m^3	flow rate (m^3/qtr)	dpm/qtr	Ci/qtr
1st - 3rd Q 1963	*Monitoring Data Not Available*				
4th Q 1963	281(all)	1329	4.07E+08	5.40E+11	2.43E-01

1963 Release Totals for 93.5% Enriched Uranium (Ci) **1.86** *

Releases by Isotope	U-234	U-235	U-238
Ci	1.81	0.05	0.0004
kg	0.29	22.06	1.09

1963 Release Totals for Depleted Uranium (Ci) **0.97** *

Releases by Isotope	U-234	U-235	U-238
Ci	0.26	0.01	0.70
kg	0.04	5.16	2061.77

Total Uranium Release Estimates for 1963 (93.5% Enriched + Depleted)

Releases by Isotope	U-234	U-235	U-234/235	U-238	Total
Ci	2.07	0.06	2.13	0.70	2.83
kg	0.33	27.21	27.54	2062.86	2090.41

* Sum of indivdual quarterly stack releases multiplied by a factor of 4 for sample line losses

D.6 AIRBORNE RELEASE ESTIMATES FOR 1960, 1961, AND 1962

Monthly stack sampling results presented in Y-12 health physics reports for 1960, 1961, and 1962 were used by the project team to derive enriched and depleted uranium release estimates for these three years. Monthly release totals, in units of microcuries, are presented in these reports and were used as the basis for the Task 6 release estimates for this operating period. Reported uranium releases per stack are based on sample measurements collected from Y-12's continuous or periodic stack monitoring. Samples were collected in exhaust stacks down-stream of exhaust filters in Buildings 9206, 9212, 9215, and 9998.

Total microcuries released per stack were then summed across all stacks to arrive at the total curies released per year for either enriched or depleted exhaust stacks. Quarterly estimates could not be verified, since daily stack monitoring data were not available to the project team. Separate totals were derived for enriched and depleted stacks. Total curies per year were then multiplied by a factor of 4 to correct for sample line losses and by a factor of 3 to correct for alpha burial losses. These corrections were made by the project team since information was not found that would document that these corrections had been applied to the reported Y-12 release estimates. Total activity was then separated into activity per uranium isotope (*i.e.*, ^{234}U, ^{235}U, and ^{238}U) based on the enrichment level. For 93.5 percent ^{235}U by weight enrichment, an average of 97.4 percent of the total activity is associated with ^{234}U; 2.6 percent from ^{235}U; and 0.02 percent from ^{238}U. For depleted uranium, an average of 26.8 percent of the total activity is associated with ^{234}U, 1.2 percent from ^{235}U, and 72 percent from ^{238}U. Once the activity of the individual uranium isotopes were determined, the project team converted these to kilograms released for each isotope by using the following specific activities: 6.29 Ci kg^{-1} for ^{234}U, 2.19×10^{-3} Ci kg^{1} for ^{235}U and 3.4×10^{4} Ci kg^{-1} for ^{238}U.

Results of the Task 6 analysis for 1958, 1959, and 1963 are presented in Tables D-8, D-9, and D-10.

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Table D-8
Task 6 1960 Air Release Estimates

			Monthly Release Estimates mCi											
Area	**Enrichment**	**Building**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
C-1 stacks	Enriched	9212	1022	1022	1022	734	2436	1488	659	739	19	1118	947	1058
C-Wing cast iron stack	Enriched	9212	300	307	160	271	1298	483	399	240	155	319	1121	1398
D-Wing cast iron stack	Enriched	9212	160	685	180	1063	639	541	5192	300	97	399	329	699
West Head House exhaust stack	Enriched	9212	7947	2705	1138	1797	4333	1855	1478	1458	1585	1398	4445	4992
Reduction exhaust stack	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1008 degreaser exhaust stack	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1009 exhaust stack	Enriched	9212	260	451	399	271	487	135	120	220	986	799	1159	559
Room 1010 sintering furnace exhaust	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1010 furnace room exhaust sta	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Dry Chemistry reactor stack	Enriched	9212	20	18	20	116	20	19	20	20	19	20	19	20
Dry Chemistry reactor stack,HF	Enriched	9212	20	20	20	20	20	20	20	20	20	20	19	20
C-2 stack	Enriched	9212	359	361	899	618	499	367	1238	459	544	319	444	419
B-1 Wing 2nd floor exhaust	Enriched	9212	46	46	46	46	46	46	60	40	39	60	19	60
B-1 Wing 2nd floor exhaust	Enriched	9212	20	20	20	20	20	20	40	20	19	20	19	40
Denitrator room and hood exhaust	Enriched	9212	20	20	20	20	20	20	20	20	19	20	19	20
B-1 Wing Calciner and Dissolver area	Enriched	9212	20	20	20	20	20	20	20	20	19	20	19	20
B-1 Wing Conversion area exhaust	Enriched	9212	30	30	30	30	30	30	60	20	19	40	19	40
B-1 Wing Feed preparation dry filter e	Enriched	9212	00	00	60	60	60	60	60	20	97	80	19	60
Reduction stack	Enriched	9212	180	253	120	135	140	19	180	120	116	40	19	20
Room 1022 E-Wing Lab	Enriched	9212	1038	126	180	174	519	58	80	20	39	60	77	140
Room 1021 E-Wing Lab	Enriched	9212	160	307	459	309	639	251	160	80	77	80	97	80
Room 1021 E-Wing Lab	Enriched	9212	20	54	20	19	20	77	20	20	19	20	19	20
Room 1021 E-Wing Lab	Enriched	9212	37	37	37	19	40	155	20	20	19	20	19	20
E-Wing exhaust stack	Enriched	9215	1018	22635	4553	4348	1238	4831	9785	4593	4116	9385	7536	2776
O-Wing Exhaust Stack	Enriched	9215	859	685	20	160	60	19	20	20	19	20	19	20
M-Wing Exhaust Stack	Enriched	9215	1078	794	779	644	1098	966	459	639	425	40	502	300
Rooms 24, 25, 26, 34, and 36	Enriched	9206	459	99	60	155	40	39	99	80	39	40	19	60
Rooms 32, 33, 34, 35, 37, 38, 39, 60-(	Enriched	9206	5871	737	160	638	280	135	40	300	193	220	116	160
Rooms 31 and 32	Enriched	9206	499	128	40	19	20	19	260	180	155	160	19	40
Dry Chemistry	Enriched	9206	80	52	20	77	40	97	80	20	58	60	19	20
Machine Shop (Filtered)	Enriched	9206	40	40	120	19	40	19	20	20	58	60	19	20
Machine Shop (Unfiltered)	Enriched	9206	40	83	20	19	20	19	20	699	19	20	19	20
Room 40, 41, 42, 43, 44, 45, and 47	Enriched	9206	539	530	100	97	1298	444	180	1977	464	439	116	180
Room 51	Enriched	9206	100	31	40	19	40	19	20	20	19	20	19	20
Monthly Total µCi			22322	32368	10840	12015	15540	12352	20906	12480	9550	15396	17315	13379
Yearly Total µCi			**194462**											
Yearly Total Ci			**2.33**	*										
Filter House	Depleted	9998	606	618	2968	2968	7575	4805	4086	1799	823	2141	2346	4878
Yearly Total µCi			**35612**											
Yearly Total Ci			**0.43**	*										

* Sum of individual monthly stack releases multipled for 4 for line losses and 3 for alpha burial loss

Totals for Buildings 9212, 9215, and 9206	**Ci (HEU)**	**kg (HEU)**	**Ci (DU)**	**kg (DU)**
U-234	2.27	0.36	0.11	0.02
U-235	0.061	27.7	0.00004	0.02
U-238	0.000467	1	0.31	905
U-234/235	2.33	28	0.1	0.04

Grand Total For 1960

Uranium (kg)	Uranium (Ci)	U-234/235 (Ci)	U-238 (Ci)
934	2.74	2.43	0.31

Table D-9
Task 6 1961 Air Release Estimates

			Monthly Release Estimates mCi											
Area	**Enrichment**	**Building**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
C-1 stacks	Enriched	9212	998	1172	699	657	998	734	2596	2716	3092	1997	1566	1566
C-Wing cast iron stack	Enriched	9212	3195	1515	599	696	359	290	1717	1378	251	280	1028	1028
D-Wing cast iron stack	Enriched	9212	799	721	180	271	200	850	1118	2316	2164	2236	2238	2238
West Head House exhaust stack	Enriched	9212	2796	3517	2796	3401	879	1140	7069	19909	16348	19709	18655	18655
Reduction exhaust stack	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1008 degreaser exhaust stack	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1009 exhaust stack	Enriched	9212	439	253	399	348	80	116	639	359	676	579	389	389
Room 1010 sintering furnace exhaust	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1010 furnace room exhaust sta	Enriched	9212	399	18	20	19	20	19	20	20	19	20	19	20
Dry Chemistry reactor stack	Enriched	9212	20	1641	349	58	319	174	379	679	309	220	19	20
C-2 stack	Enriched	9212	799	739	399	1044	599	754	419	1058	1295	919	802	802
B-1 Wing 2nd floor exhaust	Enriched	9212	20	18	20	19	20	19	80	60	58	80	39	40
B-1 Wing 2nd floor exhaust	Enriched	9212	20	18	20	19	20	19	40	40	39	60	39	40
Denitrator room and hood exhaust	Enriched	9212	20	54	60	58	40	19	80	80	116	140	116	160
B-1 Wing Calciner and Dissolver area	Enriched	9212	20	18	20	19	20	19	280	20	39	40	58	20
B-1 Wing Conversion area exhaust	Enriched	9212	60	54	60	19	20	19	60	80	77	140	329	739
B-1 Wing Feed preparation dry filter e	Enriched	9212	40	36	60	386	319	1739	11442	3455	560	240	309	280
Reduction stack	Enriched	9212	120	36	180	58	20	19	160	140	155	280	213	80
Room 1022 E-Wing Lab	Enriched	9212	140	72	479	97	20	19	140	80	58	140	77	80
Room 1021 E-Wing Lab	Enriched	9212	160	72	100	58	60	39	300	160	193	220	155	180
Room 1021 E-Wing Lab	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
Room 1021 E-Wing Lab	Enriched	9212	20	18	20	19	20	19	20	20	19	20	19	20
E-Wing exhaust stack	Enriched	9212	5791	4689	9785	1372	998	1159	2975	2177	10339	10783	10561	10561
O-Wing Exhaust Stack	Enriched	9215	20	18	20	19	20	19	160	160	77	80	19	80
M-Wing Exhaust Stack	Enriched	9215	339	505	499	251	300	715	998	1218	889	1737	1411	1617
Rooms 20 and 27	Enriched	9206	20	18	40	58	40	58	60	60	97	240	58	80
Rooms 24, 28, and 29	Enriched	9206	80	379	579	734	599	155	240	379	290	859	1932	379
Rooms 26 A and C	Enriched	9206	20	18	20	39	40	39	60	60	116	140	39	40
Dry Chemistry	Enriched	9206	20	18	20	72	260	19	80	80	97	40	97	60
Machine Shop (Filtered)	Enriched	9206	20	18	20	39	40	39	40	100	116	319	947	1917
Machine Shop (Unfiltered)	Enriched	9206	20	18	20	19	20	19	20	20	19	20	19	20
Room 30	Enriched	9206	120	90	300	135	140	1237	1118	300	232	559	676	359
Room 37	Enriched	9206	20	20	20	19	100	39	60	20	19	80	19	20
Room 51	Enriched	9206	20	20	20	20	20	20	20	20	20	20	20	20
C-Wing Rover exhaust	Enriched	9206	190	190	190	190	190	190	190	260	19	140	464	60
Monthly Total µCi			16824	16048	18071	10292	6860	9795	32659	37501	37876	42413	42409	41649
Yearly Total µCi			**312396**											
Yearly Total Ci			**3.75**	*										
Filter House	Depleted	9998	4232	5280	3499	335	3714	5950	1759	2434	7596	5493	6073	3783
Yearly Total µCi			**50149**											
Yearly Total Ci			**0.60**	*										

* Sum of individual monthly stack releases multipled for 4 for line losses and 3 for alpha burial loss

Totals for Buildings 9212, 9215, and 9206	Ci (HEU)	kg (HEU)	Ci (DU)	kg (DU)
U-234	3.65	0.58	0.16	0.03
U-235	0.097	44.5	0.00006	0.03
U-238	0.00075	2	0.43	1274
U-234/235	3.74	45.1	0.16	0.06

Grand Total For 1961

Uranium (kg)	Uranium (Ci)	U-234/235 (Ci)	U-238 (Ci)
1321	4.33	3.90	0.43

Table D-10
Task 6 1962 Air Release Estimates

			Monthly Release Estimates mCi											
Area	**Enrichment**	**Building**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
C-1 stacks	Enriched	9212	3344	1984	4792	2899	3994	3053	3344	3344	3344	3344	3344	3344
C-Wing cast iron stack	Enriched	9212	120	72	40	19	20	116	65	65	65	65	65	65
D-Wing cast iron stack	Enriched	9212	2396	2164	2197	1720	399	2222	1850	1850	1850	1850	1850	1850
West Head House exhaust stack	Enriched	9212	7588	8657	8387	5604	2197	3092	5921	5921	5921	5921	5921	5921
Reduction exhaust stack	Enriched	9212	20	18	20	19	20	19	19	19	19	19	19	19
Room 1008 degreaser exhaust stack	Enriched	9212	20	18	20	20	20	20	20	20	20	20	20	20
Room 1009 exhaust stack	Enriched	9212	419	361	319	290	140	19	258	258	258	258	258	258
Room 1010 sintering furnace exhaust stadk	Enriched	9212	20	18	20	19	20	19	19	19	19	19	19	19
Room 1010 furnace room exhaust stack	Enriched	9212	20	18	20	19	20	19	19	19	19	19	19	19
Dry Chemistry reactor stack	Enriched	9212	225	108	220	271	120	406	225	225	225	225	225	225
C-2 stack	Enriched	9212	1857	830	739	908	180	290	801	801	801	801	801	801
B-1 Wing 2nd floor exhaust	Enriched	9212	40	271	60	39	40	19	78	78	78	78	78	78
B-1 Wing 2nd floor exhaust	Enriched	9212	40	216	60	19	20	19	62	62	62	62	62	62
Denitrator room and hood exhaust	Enriched	9212	260	54	60	58	40	58	88	88	88	88	88	88
B-1 Wing Calciner and Dissolver area exhau	Enriched	9212	20	54	20	19	20	19	25	25	25	25	25	25
B-1 Wing Conversion area exhaust	Enriched	9212	120	198	140	155	40	39	115	115	115	115	115	115
B-1 Wing Feed preparation dry filter exhaust	Enriched	9212	759	379	439	754	739	580	608	608	608	608	608	608
Reduction stack	Enriched	9212	100	631	399	77	100	77	231	231	231	231	231	231
Room 1022 E-Wing Lab	Enriched	9212	140	631	220	97	20	58	194	194	194	194	194	194
Room 1021 E-Wing Lab	Enriched	9212	140	180	260	97	160	77	152	152	152	152	152	152
Room 1021 E-Wing Lab	Enriched	9212	20	18	20	19	20	19	19	19	19	19	19	19
Room 1021 E-Wing Lab	Enriched	9212	20	36	60	19	40	58	39	39	39	39	39	39
E-Wing exhaust stack	Enriched	9212	9185	12265	13579	14107	17572	6087	12132	12132	12132	12132	12132	12132
O-Wing Exhaust Stack	Enriched	9212	80	90	100	58	120	97	91	91	91	91	91	91
M-Wing Exhaust Stack	Enriched	9212	20	18	20	19	20	19	19	19	19	19	19	19
Rooms 20, 24 and 27	Enriched	9206	80	126	140	77	60	39	87	87	87	87	87	87
Rooms 24, 25, 26, 27, 28, and 29	Enriched	9206	579	271	419	367	919	870	571	571	571	571	571	571
Rooms 26 A and C	Enriched	9206	60	18	359	213	160	97	151	151	151	151	151	151
Dry Chemistry	Enriched	9206	40	595	1617	19	20	19	385	385	385	385	385	385
Machine Shop (Filtered)	Enriched	9206	200	144	80	77	80	97	113	113	113	113	113	113
Machine Shop (Unfiltered)	Enriched	9206	20	18	20	19	19	19	19	19	19	19	19	19
Room 30	Enriched	9206	579	307	300	348	200	135	311	311	311	311	311	311
Room 37	Enriched	9206	60	90	20	19	20	19	38	38	38	38	38	38
C-Wing Rover exhaust	Enriched	9206	319	36	60	39	20	19	82	82	82	82	82	82
Monthly Total µCi			28909	30896	35224	28504	27576	17818	28154	28154	28154	28154	28154	28154
Yearly Total µCi			**337853**											
Yearly Total Ci			**4.05**	*										
Filter House	Depleted	9998	4301	4255	3108	4645	4809	5231	4392	4392	4392	4392	4392	4392
Yearly Total µCi			**52699**											
Yearly Total Ci			**0.63**	*										

* Sum of individual monthly stack releases multipled for 4 for line losses and 3 for alpha burial loss

Totals for Buildings 9212, 9215, and 9206	**Ci (HEU)**	**kg (HEU)**	**Ci (DU)**	**kg (DU)**
U-234	3.94	0.63	0.17	0.03
U-235	0.105	48.1	0.00006	0.03
U-238	0.00081	2	0.46	1339
U-234/235	4.04	48.7	0.17	0.06

Grand Total For 1962

Uranium (kg)	Uranium (Ci)	U-234/235 (Ci)	U-238 (Ci)
1389.7	4.67	4.21	0.46

D.7 AIRBORNE RELEASE ESTIMATES FOR 1964-1988

Basic radiation measurement data (gross alpha counts; counts per minute, c min^{-1}) for individual air samples collected in exhaust stacks and ventilation systems were used by the project team to calculate atmospheric releases of uranium for the period 1944 through 1988. The data are stored in old computer files maintained by Y-12 (Garmeson et al. 1996).

To reconstruct uranium air releases for the period 1964 through 1988, the project team used reported radiation measurement results (net alpha counts corrected for background radiation) for 177,356 individual air samples collected from 287 stack or ventilation duct monitoring locations associated with Y-12 uranium process buildings (Garmeson et al. 1996). The data were examined and corrected for errors, such as incorrect reporting of exhaust stack air flow rates and omission of appropriate correction factors to adjust the data for biases caused by sample line and alpha burial losses. Task 6 personnel corrected over 47,000 errors (26 percent of the sample data) identified during their data evaluation, using other information collected during the investigation, such as from health physics logbooks that describe air flow measurements (Rutherford 1956; Schappel 1961; Emch 1970; Emch 1971).

The archived stack sampling data used by Task 6 investigators to reconstruct release estimates includes the following information (Garmeson et al. 1996):

- Date and frequencies of sampling for each exhaust stack;
- Sample location (stack or vent location);
- Type of uranium sampled, in terms of ^{235}U enrichment, selected from four categories:

  highly enriched. . . . . 93.5 percent or greater ^{235}U by weight;
  intermediate enriched. . . . . assumed 70 percent ^{235}U by weight;
  depleted. . . . . assumed 0.25 percent^{235} U by weight; and

- Volumetric air flow rate in the sampling line;
- Air sampling duration (usually 1 to 3 days);
- Volumetric air flow rates periodically measured in exhaust ducts and stacks and reported in health physics and operations logbooks (Rutherford 1956; Emch 1970; Emch 1971);
- Alpha activity measured on filter paper to determine uranium content;
- Counting time used to measure alpha activity on filter paper;
- Alpha counting efficiencies (calibration factors for alpha scintillation and gas proportional radiation counters);

- Correction factor of 0.3 for sample loss due to absorption of alpha particles in filter paper (also known as burial loss) (Smith et al. 1945; Struxness 1951);
- Correction factor of 0.25 to account for sample line losses due to particle deposition and impaction in the tubing or piping used to draw the samples (Schappel 1961); and
- Measured collection efficiencies of filter papers (usually reported to be between 98 and 100 percent) (Struxness 1951a; Schappel 1961).

Using the corrected measurement data, uranium release estimates for 1964 to 1988 were calculated and reported in Statistical Analysis Software (SAS) output files. Tables D-16 through D-19 provide examples of SAS output files used by the project team to complete the Y-12 air source term. A complete data set for this analysis is stored in electronic files in the project information repository. The general formula used to derive annual releases based on individual sampling results is the following:

$$\textit{Daily Release}\ (\mathrm{F}Ci) = \frac{F_s \times \left(\frac{C_{R1}}{Eff_1} \% \frac{C_{R2}}{Eff_2} \right) \times 1440}{2 \times S_s \times S_t \times (2.22 \times 10^6) \times A \times B}$$

where:

F_s	=	exhaust stack flow rate, $ft^3\ min^{-1}$;
C_{R1}	=	first alpha count rate measurement, c min^{-1};
Eff_1	=	counter efficiency for 1st measurement, dimensionless;
C_{R2}	=	second alpha count rate, c min^{-1};
Eff_2	=	counter efficiency for 2nd measurement, dimensionless;
1440	=	conversion factor, min day^{-1};
S_s	=	stack sampling flow rate, $ft^3\ min^{-1}$;
S_t	=	sample collection time, min;
A	=	sample burial loss factor (0.3);
B	=	sample line loss factor (0.25); and
2.22×10^6	=	disintegrations min^{-1} per microcurie (µCi).

Release totals were determined by the following steps: two separate alpha counts rates (C_{R1} and C_{R2}) were converted to disintegrations per minute using their respective counter detection efficiencies (Eff_1 and Eff_2) and then averaged. The average activity was then converted to activity released by incorporating the sample collection time, sampling flow rate, exhaust stack flow rate, conversions from d min^{-1} per day to microcuries per year, and sample line and alpha burial loss factors.

A summary of the Task 6 release estimates is presented in Tables D-11 through D-15. Sample output data used to create the summary tables (D-11 through D-15) are contained in Tables D-16 through D-19. For periods for which monitoring data were absent, average air concentrations were determined from air samples collected during preceding or subsequent monitoring periods. Task 6 release estimates were then compared to DOE estimates. For 1964 to 1973, Task 6 estimates are higher than those reported by DOE. However, Task 6 estimates for 1974 through 1988 were lower than those reported by DOE. Based on discussions with Y-12 workers, it was determined that unmonitored release sources were almost exclusively associated with depleted uranium operations, and would account for the majority of the differences between the Task 6 and DOE release estimates. For the purposes of the Task 6 evaluation, the project team assumed the balance of uranium released (DOE estimate minus Task 6 estimate) was depleted uranium and added the balance as depleted uranium to the Task 6 release totals (Owings et al. 1986; Owings 1996).

D.7.1 References

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Table D-11
Task 6 Air Release for 1964-1988 for 93% Enriched Uranium

	Total Activity (µCi)	U-234 (µCi)	U- 235 (µCi)	U-234/235 (Ci)	U238 (Ci)	U-234 (kg)	U-235 (kg)	U-234/235 (kg)	U-238 (kg)	TOTAL (Ci)	TOTAL (kg)
1964	546516	531760	14209	0.546	1.09E-04	0.085	6.488	6.573	0.321	0.55	6.894
1965	3348972	3258550	87073	3.346	6.70E-04	0.518	39.759	40.278	1.970	3.35	42.248
1966	1000875	973851	26023	1.000	2.00E-04	0.155	11.883	12.037	0.589	1.00	12.626
1967	480419	467448	12491	0.480	9.61E-05	0.074	5.704	5.778	0.283	0.48	6.061
1968	220628	214671	5736	0.220	4.41E-05	0.034	2.619	2.653	0.130	0.22	2.783
1969	961009	935062	24986	0.960	1.92E-04	0.149	11.409	11.558	0.565	0.96	12.123
1970	1585222	1542421	41216	1.584	3.17E-04	0.245	18.820	19.065	0.932	1.58	19.998
1971	2060245	2004618	53566	2.058	4.12E-04	0.319	24.460	24.778	1.212	2.06	25.990
1972	3428529	3335959	89142	3.425	6.86E-04	0.530	40.704	41.234	2.017	3.43	43.251
1973	3224752	3137684	83844	3.222	6.45E-04	0.499	38.285	38.784	1.897	3.22	40.680
1974	260917	253872	6784	0.261	5.22E-05	0.040	3.098	3.138	0.153	0.26	3.291
1975	502618	489047	13068	0.502	1.01E-04	0.078	5.967	6.045	0.296	0.50	6.341
1976	294508	286556	7657	0.294	5.89E-05	0.046	3.496	3.542	0.173	0.29	3.715
1977	149712	145670	3893	0.150	2.99E-05	0.023	1.777	1.801	0.088	0.15	1.889
1978	143081	139218	3720	0.143	2.86E-05	0.022	1.699	1.721	0.084	0.14	1.805
1979	212521	206783	5526	0.212	4.25E-05	0.033	2.523	2.556	0.125	0.21	2.681
1980	447098	435026	11625	0.447	8.94E-05	0.069	5.308	5.377	0.263	0.45	5.640
1981	259490	252484	6747	0.259	5.19E-05	0.040	3.081	3.121	0.153	0.26	3.273
1982	461590	449127	12001	0.461	9.23E-05	0.071	5.480	5.551	0.272	0.46	5.823
1983	396742	386030	10315	0.396	7.93E-05	0.061	4.710	4.772	0.233	0.40	5.005
1984	291561	283689	7581	0.291	5.83E-05	0.045	3.461	3.507	0.172	0.29	3.678
1985	233775	227463	6078	0.234	4.68E-05	0.036	2.775	2.812	0.138	0.23	2.949
1986	269704	262422	7012	0.269	5.39E-05	0.042	3.202	3.244	0.159	0.27	3.402
1987	541053	526445	14067	0.541	1.08E-04	0.084	6.423	6.507	0.318	0.54	6.825
1988	287384	279625	7472	0.287	5.75E-05	0.044	3.412	3.456	0.169	0.29	3.625

Table D-12
Task 6 Air Release Estimates for 1964-1988 for 70% Enriched Uranium

	Total Activity (µCi)	U-234 (µCi)	U- 235 (µCi)	U-234/235 (Ci)	U238 (Ci)	U-234 (kg)	U-235 (kg)	U-234/235 (kg)	U-238 (kg)	TOTAL (Ci)	TOTAL (kg)
1964	117809	111506	5596	1.17E-01	7.02E-04	1.77E-02	2.555	2.573	2.065	0.118	4.638
1965	63039	59666	2994	6.27E-02	3.76E-04	9.49E-03	1.367	1.377	1.105	0.063	2.482
1966	86988	82334	4132	8.65E-02	5.18E-04	1.31E-02	1.887	1.900	1.525	0.087	3.425
1967	22442	21241	1066	2.23E-02	1.34E-04	3.38E-03	0.487	0.490	0.393	0.022	0.884
1968*	0	0	0	0	0	0	0	0	0	0	0
1969	5781	5472	275	5.75E-03	3.45E-05	8.70E-04	0.125	0.126	0.101	0.006	0.228
1970	3614	3421	172	3.59E-03	2.15E-05	5.44E-04	0.078	0.079	0.063	0.004	0.142
1971	13840	13100	657	1.38E-02	8.25E-05	2.08E-03	0.300	0.302	0.243	0.014	0.545
1972	236726	224061	11244	2.35E-01	1.41E-03	3.56E-02	5.134	5.170	4.150	0.237	9.320
1973	6980	6607	332	6.94E-03	4.16E-05	1.05E-03	0.151	0.152	0.122	0.007	0.275
1974	21785	20620	1035	2.17E-02	1.30E-04	3.28E-03	0.473	0.476	0.382	0.022	0.858
1975	17938	16978	852	1.78E-02	1.07E-04	2.70E-03	0.389	0.392	0.314	0.018	0.706
1976	9258	8763	440	9.20E-03	5.52E-05	1.39E-03	0.201	0.202	0.162	0.009	0.364
1977	6348	6008	302	6.31E-03	3.78E-05	9.55E-04	0.138	0.139	0.111	0.006	0.250
1978	15449	14622	734	1.54E-02	9.21E-05	2.32E-03	0.335	0.337	0.271	0.015	0.608
1979	13544	12819	643	1.35E-02	8.07E-05	2.04E-03	0.294	0.296	0.237	0.014	0.533
1980	9814	9289	466	9.76E-03	5.85E-05	1.48E-03	0.213	0.214	0.172	0.010	0.386
1981	21801	20635	1036	2.17E-02	1.30E-04	3.28E-03	0.473	0.476	0.382	0.022	0.858
1982	9938	9406	472	9.88E-03	5.92E-05	1.50E-03	0.216	0.217	0.174	0.010	0.391
1983	9309	8811	442	9.25E-03	5.55E-05	1.40E-03	0.202	0.203	0.163	0.009	0.366
1984	39727	37602	1887	3.95E-02	2.37E-04	5.98E-03	0.862	0.868	0.696	0.040	1.564
1985	18307	17328	870	1.82E-02	1.09E-04	2.75E-03	0.397	0.400	0.321	0.018	0.721
1986	36444	34494	1731	3.62E-02	2.17E-04	5.48E-03	0.790	0.796	0.639	0.036	1.435
1987	21445	20298	1019	2.13E-02	1.28E-04	3.23E-03	0.465	0.468	0.376	0.021	0.844
1988	1592	1507	76	1.58E-03	9.49E-06	2.40E-04	0.035	0.035	0.028	0.002	0.063

* No monitoring data available for 1968

Table D-13
Task 6 Air Release Estimates for 1964-1988 for 0.25% Depleted Uranium

	Total Activity (µCi)	U-234 (µCi)	U- 235 (µCi)	U-234/235 (Ci)	U238 (Ci)	U-234 (kg)	U-235 (kg)	U-234/235 (kg)	U-238 (kg)	TOTAL (Ci)	TOTAL (kg)
1964	906545	10516	2266	0.0128	0.904	1.67E-03	1.035	1.037	2659.643	0.917	2660.680
1965	201061	2332	503	0.0028	0.201	3.71E-04	0.230	0.230	589.877	0.203	590.107
1966	308433	3578	771	0.0043	0.308	5.69E-04	0.352	0.353	904.888	0.312	905.241
1967	113062	1312	283	0.0016	0.113	2.09E-04	0.129	0.129	331.704	0.114	331.833
1968	148736	1725	372	0.0021	0.148	2.74E-04	0.170	0.170	436.366	0.150	436.536
1969	79802	926	200	0.0011	0.080	1.47E-04	0.091	0.091	234.125	0.081	234.216
1970	93648	1086	234	0.0013	0.093	1.73E-04	0.107	0.107	274.747	0.095	274.854
1971	186768	2167	467	0.0026	0.186	3.44E-04	0.213	0.214	547.943	0.189	548.156
1972	279887	3247	700	0.0039	0.279	5.16E-04	0.320	0.320	821.139	0.283	821.459
1973	125872	1460	315	0.0018	0.126	2.32E-04	0.144	0.144	369.286	0.127	369.430
1974	69360	805	173	0.0010	0.069	1.28E-04	0.079	0.079	203.490	0.070	203.569
1975	69020	801	173	0.0010	0.069	1.27E-04	0.079	0.079	202.493	0.070	202.571
1976	69360	805	173	0.0010	0.069	1.28E-04	0.079	0.079	203.490	0.070	203.569
1977	69360	805	173	0.0010	0.069	1.28E-04	0.079	0.079	203.490	0.070	203.569
1978	69360	805	173	0.0010	0.069	1.28E-04	0.079	0.079	203.490	0.070	203.569
1979	69360	805	173	0.0010	0.069	1.28E-04	0.079	0.079	203.490	0.070	203.569
1980	73440	852	184	0.0010	0.073	1.35E-04	0.084	0.084	215.460	0.074	215.544
1981	68680	797	172	0.0010	0.069	1.27E-04	0.078	0.079	201.495	0.069	201.574
1982	68340	793	171	0.0010	0.068	1.26E-04	0.078	0.078	200.498	0.069	200.576
1983	69020	801	173	0.0010	0.069	1.27E-04	0.079	0.079	202.493	0.070	202.571
1984	110840	1286	277	0.0016	0.111	2.04E-04	0.127	0.127	325.185	0.112	325.312
1985	70380	816	176	0.0010	0.070	1.30E-04	0.080	0.080	206.483	0.071	206.563
1986	70720	820	177	0.0010	0.071	1.30E-04	0.081	0.081	207.480	0.072	207.561
1987	49457	574	124	0.0007	0.049	9.12E-05	0.056	0.057	145.098	0.050	145.155
1988	48272	560	121	0.0007	0.048	8.90E-05	0.055	0.055	141.622	0.049	141.677

Table D-14
Task 6 Air Release Estimates for 1964-1988 for >95% Enriched Uranium

	Total Activity (µCi)	U-234 (µCi)	U- 235 (µCi)	U-234/235 (Ci)	U238 (Ci)	U-234 (kg)	U-235 (kg)	U-234/235 (kg)	U-238 (kg)	TOTAL (Ci)	TOTAL (kg)
1964*	0	0	0	0	0	0	0	0	0	0	0
1965*	0	0	0	0	0	0	0	0	0	0	0
1966*	0	0	0	0	0	0	0	0	0	0	0
1967*	0	0	0	0	0	0	0	0	0	0	0
1968*	0	0	0	0	0	0	0	0	0	0	0
1969*	0	0	0	0	0	0	0	0	0	0	0
1970*	0	0	0	0	0	0	0	0	0	0	0
1971*	0	0	0	0	0	0	0	0	0	0	0
1972*	0	0	0	0	0	0	0	0	0	0	0
1973*	0	0	0	0	0	0	0	0	0	0	0
1974*	0	0	0	0	0	0	0	0	0	0	0
1975*	0	0	0	0	0	0	0	0	0	0	0
1976	24331	23852	477	0.0243	7.06E-07	0.004	0.218	0.222	0.002	0.024	0.224
1977	6719	6587	132	0.0067	1.95E-07	0.001	0.060	0.061	0.001	0.007	0.062
1978	11887	11653	233	0.0119	3.45E-07	0.002	0.106	0.108	0.001	0.012	0.109
1979	13876	13603	272	0.0139	4.02E-07	0.002	0.124	0.126	0.001	0.014	0.128
1980	12949	12694	254	0.0129	3.76E-07	0.002	0.116	0.118	0.001	0.013	0.119
1981	11645	11416	228	0.0116	3.38E-07	0.002	0.104	0.106	0.001	0.012	0.107
1982	9223	9041	181	0.0092	2.67E-07	0.001	0.083	0.084	0.001	0.009	0.085
1983	5921	5804	116	0.0059	1.72E-07	0.001	0.053	0.054	0.001	0.006	0.054
1984	18642	18275	365	0.0186	5.41E-07	0.003	0.167	0.170	0.002	0.019	0.171
1985	29194	28619	572	0.0292	8.47E-07	0.005	0.261	0.266	0.002	0.029	0.268
1986	42726	41884	837	0.0427	1.24E-06	0.007	0.382	0.389	0.004	0.043	0.393
1987	29681	29096	582	0.0297	8.61E-07	0.005	0.266	0.270	0.003	0.030	0.273
1988	13110	12852	257	0.0131	3.80E-07	0.002	0.117	0.119	0.001	0.013	0.120

* No monitoring data available

Table D-15
Task 6 Air Release Estimates for 1964-1988 - Total Ci and kg

	U-234 (kg)	U-235 (kg)	U-234/235 (kg)	U-238 (kg)	U-234/235 (Ci)	U-238 (Ci)	TOTAL (Ci)	TOTAL (kg)
1964	0.10	10.08	10.18	2662.03	0.68	0.91	1.58	2672.21
1965	0.53	41.36	41.88	592.95	3.41	0.20	3.61	634.84
1966	0.17	14.12	14.29	907.00	1.09	0.31	1.40	921.29
1967	0.08	6.32	6.40	332.38	0.50	0.11	0.62	338.78
1968	0.03	2.79	2.82	436.50	0.22	0.15	0.37	439.32
1969	0.15	11.63	11.78	234.79	0.97	0.08	1.05	246.57
1970	0.25	19.01	19.25	275.74	1.59	0.09	1.68	294.99
1971	0.32	24.97	25.29	549.40	2.07	0.19	2.26	574.69
1972	0.57	46.16	46.72	827.31	3.66	0.28	3.95	874.03
1973	0.50	38.58	39.08	371.31	3.23	0.13	3.36	410.39
1974	0.04	3.65	3.69	204.03	0.28	0.07	0.35	207.72
1975	0.08	6.44	6.52	203.10	0.52	0.07	0.59	209.62
1976	0.05	3.99	4.05	203.83	0.33	0.07	0.40	207.87
1977	0.03	2.05	2.08	203.69	0.16	0.07	0.23	205.77
1978	0.03	2.22	2.25	203.85	0.17	0.07	0.24	206.09
1979	0.04	3.02	3.06	203.85	0.24	0.07	0.31	206.91
1980	0.07	5.72	5.79	215.90	0.47	0.07	0.54	221.69
1981	0.05	3.74	3.78	202.03	0.29	0.07	0.36	205.81
1982	0.07	5.86	5.93	200.94	0.48	0.07	0.55	206.87
1983	0.06	5.04	5.11	202.89	0.41	0.07	0.48	208.00
1984	0.05	4.62	4.67	326.05	0.35	0.11	0.46	330.73
1985	0.04	3.51	3.56	206.94	0.28	0.07	0.35	210.50
1986	0.05	4.46	4.51	208.28	0.35	0.07	0.42	212.79
1987	0.09	7.21	7.30	145.79	0.59	0.05	0.64	153.10
1988	0.05	3.62	3.67	141.82	0.30	0.05	0.35	145.49
TOTAL	3.51	280.15	283.66	10262.40	22.67	3.49	26.16	10546.06

TABLE D-16: Example of Stack Measurement Data Used to Estimate Highly-Enriched Uranium Releases (1964-1988)

Product Code 1 = highly-enriched uranium

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AREA/LOC	YEAR	PROD CODE	FLOW RATE	TOTAL SAMPLE TIME	EFF-1	EFF-2	TOTAL MICROCURIE FOR THE YEAR	STACK RATE	COUNT-1	COUNT-2	SAMPLES COLLECTED
20JF11	65	1	0.85	348480.0	.08	.08	119328.21	44000	250566	248801	121
TOTALS	65	1					3348971.68		12831477	12751621	3781
11NF03	66	1	0.81	488160.0	.09	.08	80697.71	52000	240519	225764	146
11NF04	66	1	0.67	489600.0	.09	.08	15851.77	41000	40907	37904	147
11NF14	66	1	0.81	492480.0	.09	.08	65738.21	28000	251455	439596	248
11NF16	66	1	0.36	496800.0	.09	.08	140.05	1000	8716	8603	149
11NF18	66	1	0.36	364320.0	.09	.08	245.35	1000	10421	9193	101
11NF20	66	1	0.36	364320.0	.09	.08	423.74	1000	20600	21171	101
11NF21	66	1	0.36	493920.0	.09	.08	375.98	1000	25661	24434	148
11NF22	66	1	0.81	492480.0	.09	.08	110722.75	7000	2360638	2024838	248
11NF23	66	1	0.81	493920.0	.09	.08	16158.45	15000	166530	167024	148
11NF25	66	1	0.52	485280.0	.09	.08	1662.00	10000	14572	13352	145
11NF27	66	1	0.52	491040.0	.09	.08	20442.29	15000	135789	121771	147
11NF28	66	1	0.52	491040.0	.09	.08	457.88	4000	10082	9132	147
11NF29	66	1	0.52	485280.0	.09	.08	256.64	4000	5853	5701	145
11NF30	66	1	0.52	488160.0	.09	.08	6476.85	10000	61540	58048	146
11NF31	66	1	0.52	488160.0	.09	.08	6061.91	10000	57425	52849	146
11NF32	66	1	0.52	491040.0	.09	.08	10090.98	10000	83698	75345	147
11NF33	66	1	0.52	493920.0	.09	.08	1925.97	10000	18053	16783	148
11NF34	66	1	0.52	488160.0	.09	.08	3245.90	10000	26111	26845	146
11NF35	66	1	0.52	479520.0	.09	.08	9271.11	4000	207334	198470	144
11NF38	66	1	0.6	493920.0	.09	.08	2524.84	14000	19784	18875	148
11NF43	66	1	1.2	266400.0	.10	.09	13555.12	1000	1836640	1642211	133
11NF44	66	1	1.2	122400.0	.09	.10	1866.76	1000	99596	115824	61
13JF01	66	1	0.91	423360.0	.09	.08	430804.89	70000	900977	855801	147
13JF19	66	1	0.6	279360.0	.09	.09	71260.15	14000	79075	474074	97
13JF37	66	1	0.6	426240.0	.09	.08	2250.25	40000	5152	5207	148
15DF36	66	1	0.7	423360.0	.09	.08	3471.03	40000	9654	9223	147
17FF05	66	1	0.75	423360.0	.09	.08	9898.72	56000	20961	19040	147
20GF01	66	1	1.2	311040.0	.08	.07	23497.47	10000	129833	424819	108
20JF11	66	1	0.85	411840.0	.09	.08	91500.60	44000	262043	242198	143
TOTALS	66	1					1000875.37		7109619	7344095	4176
11NF03	67	1	0.81	342720.0	.11	.12	65600.65	52000	159355	184819	102
11NF04	67	1	0.67	345600.0	.11	.12	10396.11	41000	28615	30712	103
11NF14	67	1	0.81	344160.0	.11	.12	42085.23	28000	202780	202709	171
11NF16	67	1	0.36	348480.0	.11	.12	69.13	1000	4167	4186	104
11NF18	67	1	0.36	93600.0	.11	.12	85.21	1000	1337	1350	26
11NF20	67	1	0.36	90720.0	.10	.12	122.90	1000	1690	1960	25
11NF21	67	1	0.36	345600.0	.11	.12	62.96	1000	3825	3858	103
11NF22	67	1	0.81	339840.0	.12	.12	66935.88	7000	1394203	1281090	170
11NF23	67	1	0.81	341280.0	.11	.12	3429.05	15000	30104	32480	102
11NF25	67	1	0.52	344160.0	.11	.12	685.73	10000	6261	5774	103
11NF27	67	1	0.52	344160.0	.11	.12	6536.23	15000	39393	41600	103
11NF28	67	1	0.52	344160.0	.11	.12	232.02	4000	4843	4745	103
11NF29	67	1	0.52	344160.0	.11	.12	153.60	4000	3323	3279	103
11NF30	67	1	0.52	344160.0	.11	.12	2100.50	10000	17828	19022	103
11NF31	67	1	0.52	344160.0	.11	.12	2250.83	10000	18983	20177	103

TABLE D-17: Example of Stack Measurement Data Used to Estimate Intermediate Enriched Uranium Releases (1964-1988)

Product Code 2 = intermediate enriched uranium

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AREA/LOC	YEAR	PROD CODE	FLOW RATE	TOTAL SAMPLE TIME	EFF-1	EFF-2	TOTAL MICROCURIE FOR THE YEAR	STACK RATE	COUNT-1	COUNT-2	SAMPLES COLLECTED
12PA01	64	2	1	17280.0	.16	.16	1972.45	39000	593	585	6
12PA02	64	2	1	17280.0	.16	.16	1791.96	82000	261	248	6
12PA03	64	2	1	17280.0	.16	.16	31.68	3000	122	124	6
12PA04	64	2	1	17280.0	.16	.16	6452.14	11000	7057	6605	6
12PA05	64	2	1	17280.0	.16	.16	323.55	6000	679	577	6
12PA07	64	2	1	17280.0	.16	.16	44636.39	78000	6894	6435	6
12PF01	64	2	1	123840.0	.14	.14	2291.26	39000	4503	4544	43
12PF02	64	2	1	123840.0	.14	.14	3588.11	82000	3309	3338	43
12PF03	64	2	1	120960.0	.14	.14	33.52	3000	733	834	42
12PF04	64	2	1	123840.0	.14	.14	23137.32	11000	153114	154641	43
12PF05	64	2	1	123840.0	.14	.14	606.44	6000	7231	7193	43
12PF07	64	2	1	129600.0	.14	.14	32944.48	78000	33191	31701	47
TOTALS	64	2					117809.30		217687	216825	297
12PF01	65	2	1	303840.0	.07	.07	2889.82	39000	5683	5756	91
12PF02	65	2	1	302400.0	.08	.07	5468.56	82000	6388	6542	90
12PF03	65	2	1	302400.0	.08	.07	73.54	3000	2352	2282	90
12PF04	65	2	1	129600.0	.07	.07	13147.30	11000	46579	46569	43
12PF05	65	2	1	302400.0	.08	.07	649.14	6000	10343	10407	90
12PF07	65	2	1	298080.0	.08	.07	40810.88	78000	48269	47060	89
TOTALS	65	2					63039.23		119614	118616	493
12PF01	66	2	1	266400.0	.08	.08	1026.78	39000	2314	2328	73
12PF02	66	2	1	262080.0	.08	.08	3827.63	82000	4773	4149	72
12PF03	66	2	1	264960.0	.08	.08	129.66	3000	3806	3695	73
12PF04	66	2	1	214560.0	.08	.07	61033.33	11000	393779	353325	59
12PF05	66	2	1	21600.0	.11	.09	817.87	6000	1290	1118	6
12PF06	66	2	1	28800.0	.07	.06	8208.12	11000	6732	5942	8
12PF07	66	2	1	262080.0	.08	.08	10947.02	78000	15097	13184	72
12P602	66	2	1	4320.0	.08	.09	956.39	82000	8	28	1
12P603	66	2	1	4320.0	.08	.09	41.20	3000	12	30	1
TOTALS	66	2					86988.01		427811	383799	365
12PF01	67	2	1	184320.0	.12	.12	724.60	39000	1746	1668	51
12PF02	67	2	1	174240.0	.12	.12	2809.62	82000	3000	2962	48
12PF03	67	2	1	184320.0	.12	.12	229.76	8000	2610	2651	51
12PF06	67	2	1	184320.0	.12	.12	12784.22	11000	107845	100640	51
12PF07	67	2	1	184320.0	.11	.12	5894.07	78000	7146	7201	51
TOTALS	67	2					22442.28		122347	115122	252
12PF01	69	2	1	325440.0	.11	.11	707.04	39000	3368	2317	90
12PF02	69	2	1	321120.0	.11	.11	1327.20	82000	2952	1924	89
12PF03	69	2	1	325440.0	.11	.11	199.29	8000	4491	3295	90
12PF06	69	2	1	292320.0	.11	.11	1502.89	11000	13898	14646	81
12PF07	69	2	1	325440.0	.11	.11	2045.04	78000	4344	3557	90
TOTALS	69	2					5781.45		29053	25739	440

TABLE D-18: Example of Stack Measurement Data Used to Estimate Depleted Uranium Releases (1964-1988)

Product Code 3 = depleted uranium

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AREA/LOC	YEAR	PROD CODE	FLOW RATE	TOTAL SAMPLE TIME	EFF-1	EFF-2	TOTAL MICROCURIE FOR THE YEAR	STACK RATE	COUNT-1	COUNT-2	SAMPLES COLLECTED
15AE02	64	3	0.65	10080.0	.16	.16	299737.01	112000	12895	10740	5
15AE04	64	3	0.65	10080.0	.16	.16	12758.00	112000	551	455	5
15EF02	64	3	0.65	172800.0	.14	.14	476058.04	112000	288545	270633	116
15EF04	64	3	0.65	171360.0	.14	.14	117992.43	112000	67203	65144	115
TOTALS	64	3					906545.48		369194	346972	241
15EF02	65	3	0.65	358560.0	.08	.08	17268.08	112000	11155	11231	249
15EF04	65	3	0.65	348480.0	.08	.08	183793.04	112000	111629	108828	242
TOTALS	65	3					201061.11		122784	120059	491
15EF02	66	3	0.65	361440.0	.09	.08	131715.26	112000	99107	88392	251
15EF04	66	3	0.65	365760.0	.09	.08	176717.88	112000	133324	113627	254
TOTALS	66	3					308433.14		232431	202019	505
15EF02	67	3	0.65	247680.0	.12	.12	21698.46	112000	16129	16249	172
15EF04	67	3	0.65	247680.0	.12	.12	91364.00	112000	72241	62652	172
TOTALS	67	3					113062.45		88370	78901	344
15EF02	69	3	0.65	260640.0	.11	.11	45510.52	112000	33269	31118	181
15EF04	69	3	0.65	264960.0	.11	.11	34291.51	112000	25790	24192	184
TOTALS	69	3					79802.04		59059	55310	365
15EF02	70	3	0.65	53280.0	.13	.12	93648.32	112000	15003	15591	37
TOTALS	70	3					93648.32		15003	15591	37
15EF02	71	3	0.65	223200.0	.12	.11	16162.41	112000	9985	9510	155
15EF04	71	3	0.65	1440.0	.13	.11	20167.04	112000	109	59	1
TOTALS	71	3					36329.45		10094	9569	156
15E 02	72	3	0.65	56160.0	.08	.07	9.91	112	849	734	39
15EF02	72	3	0.65	290880.0	.07	.07	15541.11	112000	8277	8564	202
16GF01	72	3	0.812	75.0	.09	.09	264336.28	2000	3384	3165	5
TOTALS	72	3					279887.29		12510	12463	246
15EF02	73	3	0.65	473760.0	.10	.11	1351.42	38400	3766	3905	243
TOTALS	73	3					1351.42		3766	3905	243
15EF02	74	3	0.65	488160.0	.11	.12	913.43	38400	3652	3440	243
TOTALS	74	3					913.43		3652	3440	243
15EF02	75	3	1	466560.0	.11	.12	1293.37	42000	6552	6472	232
TOTALS	75	3					1293.37		6552	6472	232

TABLE D-19: Example of Stack Measurement Data Used to Estimate Unknown Enriched Uranium Releases (1964-1988)

Product Code 5 = unknown enriched uranium

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AREA/LOC	YEAR	PROD CODE	FLOW RATE	TOTAL SAMPLE TIME	EFF-1	EFF-2	TOTAL MICROCURIE FOR THE YEAR	STACK RATE	COUNT-1	COUNT-2	SAMPLES COLLECTED
12PF03	76	5	1	468000.0	.11	.11	23929.31	46100	105349	108058	231
12PF07	76	5	1	465120.0	.11	.11	401.47	10100	8186	8153	231
TOTALS	76	5					24330.79		113535	116211	462
12PF03	77	5	1	440640.0	.13	.12	6321.94	46100	35055	32985	222
12PF07	77	5	1	444960.0	.13	.12	397.29	10100	9780	8913	223
TOTALS	77	5					6719.23		44835	41898	445
12PF03	78	5	1	465120.0	.15	.15	11434.89	46100	71488	70707	235
12PF07	78	5	1	460800.0	.15	.15	451.61	10100	13003	13070	232
TOTALS	78	5					11886.50		84491	83777	467
12PF03	79	5	1	488160.0	.16	.15	13374.28	46100	93063	90441	243
12PF07	79	5	1	482400.0	.16	.15	501.68	10100	16035	15356	239
TOTALS	79	5					13875.97		109098	105797	482
12PF03	80	5	1	480960.0	.16	.16	12586.50	46100	87998	86123	242
12PF07	80	5	1	476640.0	.16	.16	362.31	10100	11360	11286	241
TOTALS	80	5					12948.81		99358	97409	483
12PF03	81	5	1	470880.0	.16	.16	11400.33	46100	76146	76458	236
12PF07	81	5	1	488160.0	.16	.16	244.63	10100	7879	7723	242
TOTALS	81	5					11644.96		84025	84181	478
12PF03	82	5	1	455760.0	.16	.16	8880.06	46100	58108	59508	227
12PF07	82	5	1	454320.0	.16	.16	343.00	10100	9909	10758	226
TOTALS	82	5					9223.06		68017	70266	453
12PF03	83	5	1	459360.0	.17	.17	4891.35	46100	35634	34366	233
12PF07	83	5	1	466560.0	.17	.17	1029.99	10100	35326	33881	236
TOTALS	83	5					5921.35		70960	68247	469
12PF03	84	5	1	465120.0	.16	.15	18129.32	46100	123620	117246	233
12PF07	84	5	1	469459.7	.16	.15	512.53	10100	15892	15871	239
TOTALS	84	5					18641.85		139512	133117	472
12PF03	85	5	1	470880.0	.15	.15	28965.41	46100	193985	187367	237
12PF07	85	5	1	485280.0	.15	.15	229.08	10100	6846	7208	243
TOTALS	85	5					29194.49		200831	194575	480
12PF03	86	5	0.5	459360.0	.16	.15	42418.98	46100	138813	139106	226

APPENDIX E

URANIUM ACCOUNTABILITY RECORDS DATABASE AND REFERENCE LIST

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Appendix E contains all of the release information for the K-25/S-50 complex obtained from the review of historical records maintained by the K-25 Uranium Accountability Division. These data are the bulk of the information contained in the airborne release database. The remainder of the data are from environmental monitoring records for 1973 to 1985, from environmental monitoring records for 1986 to 1995, and from the estimated releases from the cylinder fire tests conducted in 1965. The environmental monitoring records data account for 984 kg of the total atmospheric release (10, 712 kg) reported by DOE/K-25, or approximately 9%. The releases from the cylinder fire tests are summarized in Table 2-2 of Section 2, and sum to 187 kg of uranium. These releases were not included in DOE/K-25's assessments.

Appendix E provides listings of the release information from the following spreadsheets (see section 2.2.1 of the final report for details).

- *Atmospheric Release (Table E-1)*
- *New Data 10-31-96 (Table E-2)*
- *New Data 8-29-96 (Table E-3)*
- *New Data 11-6-97 (Table E-4)*

A cross-reference between the reference citations used in the spreadsheets and the corresponding formal reference citations is included.

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
11/28/44	S-50	UF_6	58269	0.711	414	57851	3.9E-02	break in link line from No. 1 scale tank	EIVA	3357
3/1/45	S-50	UF_6	899774	0.711	6397	893320	6.0E-01	reported losses	EIVA	2368
4/1/45	S-50	UF_6	1233475	0.711	8770	1224627	8.3E-01	reported losses	EIVA	2368
4/28/45	K-302-5	UF_6	9200	0.8	76	9124	6.6E-03	Product drain line valve bellows rupture	EIVA	652
5/1/45	S-50	UF_6	367475	0.711	2613	364839	2.5E-01	reported losses	EIVA	2368
6/1/45	S-50	UF_6	366124	0.711	2603	363498	2.5E-01	reported losses	EIVA	2368
7/1/45	S-50	UF_6	166850	0.711	1186	165653	1.1E-01	reported losses	EIVA	2368
12/1/45	Cascade	UF_6	6	30	2	4	9.4E-05	Purge cascade calculations	ESA	3189
1/1/46	Cascade	UF_6	18	30	6	13	2.7E-04	Purge cascade calculations	ESA	3189
2/1/46	Cascade	UF_6	12	30	4	9	1.9E-04	Purge cascade calculations	ESA	3189
3/1/46	Cascade	UF_6	6	30	2	4	8.7E-05	Purge cascade calculations	ESA	3189
4/1/46	Cascade	UF_6	1	30	0.3	0.8	1.6E-05	Purge cascade calculations	ESA	3189
5/1/46	Cascade	UF_6	5	30	2	4	7.7E-05	Purge cascade calculations	ESA	3189
7/1/46	Cascade	UF_6	183	30	55	128	2.7E-03	Vaporized	EIVA	631
8/31/46	K-306-7	UF_6	4	60	2	2	1.4E-04	Vaporized solid material on cylinder gasket.	CIVA	631
9/14/46	K-306-7	UF_6	15	60	9	6	5.3E-04	Vaporized solid material in product line	EIVA	631
9/24/46	K-312-3	UF_6	12	60	7	5	4.3E-04	Vaporized solid material from cylinder flange.	CIVA	631
10/1/46	Cascade	UF_6	0.3	60	0.2	0.1	9.3E-06	Purge cascade calculations	ESA	3189
11/9/46	K-306-7	UF_6	1183	60	710	473	4.2E-02	Release from cylinder valve during cap removal	CIVA	652, 631
12/28/46	K-306-5	UF_6	4	93	4	0.3	2.6E-04	Valve seat failure on cylinder.	CIVA	631
3/27/47	K-306-7	UF_6	6	93.5	6	0.4	3.9E-04	Leak from sample tube.	EIVA	631
8/8/47	K-306-7	UF_6	4	93.5	4	0.3	2.6E-04	Cylinder plug leak when opened to atmosphere.	CIVA	631
9/24/47	K-303-9	UF_6	306	45	138	168	7.5E-03	Glass trap on line recorder broke.	EIVA	631

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
3/16/48	K-131	UF_6	1	0.725	0.007	1	6.8E-07	Leak around cylinder valve stem.	CIVA	631
3/24/48	K-306-7	UF_6	1	93.5	0.9	0.1	6.6E-05	Vaporized solid material.	EIVA	631
4/19/48	K-301-3	UF_6	1	15	0.2	0.9	6.9E-06	Leak from LR manifold.	EIVA	631
4/21/48	K-1004-B	UF_6	1	0.711	0.01	1	6.7E-07	Material stuck to sample tube gasket.	EIVA	631
4/21/48	K-306-7	UF_6	9	93.5	8	0.6	5.9E-04	Leak around cylinder gasket.	CIVA	631
5/10/48	K-1004-A	UF_6	1	0.4	0.004	1	5.5E-07	Operator error.	EIVA	631
5/11/48	K-1004-A	UF_6	75	0.4	0.3	75	4.1E-05	Gasket failure.	EIVA	631
5/21/48	K-1004-A	UF_6	1	0.4	0.004	1	5.5E-07	Faulty connection.	EIVA	631
9/28/48	K-1405	UF_6	4517	0.711	32	4485	3.0E-03	Powder blown to atmosphere	EIVA	652, 631
2/23/49	K-1005	UF_6	12	0.711	0.1	12	8.1E-06	Broken glass container.	EIVA	631
3/10/49	K-1024	UF_6	1	93.5	0.9	0.1	6.6E-05	Broken chemical trap.	EIVA	631
5/23/49	K-1004-A	UF_6	10	0.4	0.04	10	5.5E-06	Cylinder leaked.	CIVA	631
9/4/49	K-631	UF_6	45081	0.4	180	44901	2.5E-02	Kerotest cylinder valve broke off near weld.	CIVA	652, 631
9/19/49	K-1004-A	UF_6	20	0.711	0.1	20	1.3E-05	Gasket failed.	EIVA	631
11/1/49	K-1405	UF_6	18400	0.7115	131	18269	1.2E-02	Material escaped the during conversion of UF4 to UF6	EIVA	2313
12/20/49	K-631	UF_6	6322	0.4	25	6297	3.5E-03	Released from an opened compressor	EIVA	2313
12/30/49	K-631	UF_6	7820	0.4	31	7789	4.3E-03	Valve bellows rupture in surge drum evacuation line	EIVA	2313
4/14/50	K-1405	UF_6	9200	0.711	65	9135	6.2E-03	Cold trap leak due to defective valve.	EIVA	652, 631
4/17/50	K-1405	UF_6	3373	0.711	24	3349	2.3E-03	Cold trap inlet valve leaked	EIVA	652, 631
6/28/50	K-1405	UF_6	122668	0.71	871	121797	8.2E-02	Hydraulic rupture of over filled cylinder	CIVA	652, 631
8/14/50	K-1004-A	UF_6	300	0.711			2.0E-04	Cylinder ruptured.	CIVA	631
3/1/51	Development	UF_6	675	0.711	5	670	4.5E-04	Misvalving operation.	EIVA	631
3/13/51	K-1401	UF_6	674	0.711	5	670	4.5E-04	high pressure	EIVA	2886

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
4/13/51	K-1004-D rm 8	UF_6	68	0.711	0.5	67	4.5E-05	blew open	CIVA	2886
4/28/51	K-1405	UF_6	28046	0.6	168	27878	1.8E-02	Valve leak on by-pass to exhaust stack	EIVA	652, 631
5/7/51	K-1405	UF_6	688	0.711	5	683	4.6E-04	broken bellows	EIVA	2886
5/23/51	K-1405	UF_6	4599	0.711	33	4566	3.1E-03	leaking from valve	EIVA	2886
6/3/51	K-1405	UF_6	10735	0.711	76	10659	7.2E-03	Line leak when purged	EIVA	652, 631
7/12/51	K-1405	UF_6	3067	0.71	22	3045	2.1E-03	Leaking gaskets in pilot plant	EIVA	652, 631
7/20/51	K-1131	UF_6	43612	0.71	310	43302	2.9E-02	Leaking valve seat on purge line	EIVA	652, 631
8/5/51	K-1131	UF_6	61334	0.6	368	60966	3.9E-02	Fracture of cylinder end plate	CIVA	652, 631, 2320
8/6/51	K-1004-A rm 19	UF_6	68	0.711	0.5	67	4.5E-05	replacing stuck valve	CIVA	2886
8/9/51	K-1405	UF_6	12269	0.71	87	12182	8.2E-03	Plugged line leaked when opened	EIVA	652, 631
8/24/51	K-602-4	UF_6	1227	0.49	6	1221	7.2E-04	Seal failure	EIVA	652, 631
9/14/51	K-1405	UF_6	3401	0.71	24	3377	2.3E-03	Spilled from barrier tube	EIVA	652
9/22/51	K-631	UF_6	14008	0.4	56	13952	7.7E-03	Thermowell leak on charge line to AC pump	EIVA	652, 631
10/18/51	K-1401 rm 204	UF_6	2298	0.711	16	2282	1.5E-03	cylinder leaking	CIVA	2886
11/1/51	Laboratory	UF_6	790	0.711	6	784	5.3E-04	A hole developed in a cylinder being heated in an oil bath.	CIVA	631
11/5/51	K-1405	UF_6	3067	0.71	22	3045	2.1E-03	Loose flange connection	EIVA	652
11/14/51	K-1405	UF_6	3066	0.71	22	3044	2.1E-03	Line cut to release plug	EIVA	652
11/21/51	K-402-8	UF_6	1534	0.52	8	1526	9.2E-04	Valving error	EIVA	652
12/1/51	Cascade	UF_6	2	93.5	2	0.1	1.3E-04	Leak on plug on cylinder head was discovered when cubicle was opened to weigh cylinder.	CIVA	631
12/1/51	K-1405	UF_6	613	0.711	4	609	4.1E-04	Leak around UF6 orifice flange.	EIVA	631
12/1/51	K-31	UF_6	1534	2	31	1503	1.8E-03	Air jets were being used to evacuate a negative cell. A UF6 line from cold trap was valved into this negative system which was being evacuated.	EIVA	631

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
12/1/51	Development	UF_6	3067	0.711	22	3045	2.1E-03	Plugged preheater in B Room.	EIVA	631
1/3/52	K-631	UF_6	1165	0.69	8	1157	7.7E-04	Plugged line vaporized when opened	EIVA	652, 2470, 2539
1/16/52	K-413	UF_6	3665	0.71	26	3639	2.5E-03	Opened valve, safety cap removed	EIVA	652, 2470, 2539
2/1/52	K-1413	UF_6	153	0.7115	1	152	1.0E-04	Dropped barrier receiver in laboratory	EIVA	631, 2470, 2539
2/28/52	K-1401	UF_6	2	0.8	0.02	2	1.8E-06	Leaking cylinder feed line to pilot plant	CIVA	2470, 2539
3/1/52	K-306-7	UF_6	8	0.507	0.04	8	4.7E-06	Bellows broke on the B-4 pump on the waste feed sample line	EIVA	2470, 2539
3/30/52	K-1401	UF_6	8586	0.8	67	8519	6.0E-03	Recovered uranium from furnace fluorination of 53 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
4/1/52	K-1004-A	UF_6	1108	0.45	5	1103	6.3E-04	Overfilled sample cylinder leaked	CIVA	652, 631, 2470, 2539
5/19/52	K-631	UF_6	1533	4.83	74	1459	3.5E-03	Faulty gasket on cylinder valve leaked	CIVA	652, 2470, 2539
5/20/52	K-1401	UF_6	7666	0.71	54	7612	5.1E-03	Stokes pump casing burst	EIVA	652
5/27/52	K-1401	UF_6	7011	0.7	50	6961	4.7E-03	Stuck valve to Stokes pump	EIVA	652, 631, 2470, 2539
6/23/52	K-306-7	UF_6	10	90	9	1	6.2E-04	Leak in the plug on the head of a product cylinder	CIVA	631, 2470, 2539
6/30/52	K-1401	UF_6	2705	0.7	19	2686	1.8E-03	Recovered uranium from furnace fluorination of 53 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
8/4/52	K-631	UF_6	1534	4.8	74	1460	3.5E-03	Faulty gasket on the condenser side of a 10 ton waste cylinder	CIVA	652, 631, 2470
8/15/52	K-1401	UF_6	268	1.1	3	265	2.2E-04	quarterly decon in K-1401	EIVA	2892

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
9/9/52	K-131	UF_6	24601	0.4	108	24493	1.4E-02	Ruptured feed pigtail	CIVA	652, 631, 2470
9/19/52	K-1131	UF_6	306718	0.7	2182	304536	2.1E-01	Cold trap rupture disk - vented to atmosphere over a period of 10 hours	ESA	652, 631, 2470
9/30/52	K-1401	UF_6	8308	0.8	70	8238	6.0E-03	Recovered uranium from furnace fluorination of 67 converters were vented to atmosphere over a three month period	ESA	631, 2470
10/3/52	K-631	UF_6	15336	0.4	69	15267	8.8E-03	Bad gasket on pigtail connection	CIVA	652, 631, 2470
10/6/52	K-1131	UF_6	15333	0.71	109	15224	1.0E-02	Ruptured cold trap tube	EIVA	652, 2470, 2320
10/10/52	K-631	UF_6	4601	0.4	20	4581	2.6E-03	Pressure instrument on feed line broke	EIVA	652, 631, 2470
10/13/52	K-402-6	UF_6	613	0.45	3	610	3.5E-04	Booster pump seal failure	EIVA	2470
11/3/52	K-413	UF_6	3067	0.5	14	3053	1.8E-03	Cut into process line	EIVA	652, 631, 2470
11/21/52	K-306-7	UF_6	293	0.7	2	291	1.9E-04	Excessive pressure caused a gasket to blow on pump and ruptured bellows	EIVA	2470
12/1/52	K-1303	Uranyl Nitrate	7488	5.3	400	7088	1.9E-02	Leak from product evaporator	EIVA	652, 631, 2470
12/3/52	K-1301	UF_6	1626	0.4	7	1619	9.2E-04	Leak from cylinders on transfer operation	CIVA	652, 631, 2470
12/30/52	K-306-7	UF_6	8588	0.5	40	8548	5.0E-03	Three separate releases on 12/24, 1/29, & 12/30 (a) bellows rupture of west B-4 pump (b) bellows rupture of west B-4 pump (c) tee in B-4 pump discharge line split	EIVA	652, 631, 2470

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
12/30/52	K-402-1	UF_6	768590	0.6	4312	764278	4.7E-01	Valve failure on a liquid feed cylinder	CIVA	652, 631, 2470, 2320
12/31/52	K-1401	UF_6	10281	0.8	83	10198	7.3E-03	Recovered uranium from furnace fluorination of 80 converters were vented to atmosphere over a three month period	ESA	631, 2470
1/1/53	Cascade	UF_6	203	93.5	190	13	1.3E-02	Purge cascade calculations	ESA	3189
1/8/53	K-131	UF_6	59197	0.6	370	58827	3.8E-02	Defective cylinder valve - lost material drained	CIVA	652, 2470, 2539
1/13/53	K-631	UF_6	128077	0.6	739	127338	7.9E-02	Hose blew off drain line - bldg exhaust fans OFF	EIVA	652, 631, 2470, 2539
1/24/53	K-306-7	UF_6	293	0.7	2	291	1.9E-04	Waste sample line blew off	EIVA	631, 2470
1/30/53	K-1401	UF_6	86	0.7115	0.6	85	5.8E-05	Valve closure failure in the barrier research pilot plant	EIVA	631, 2470, 2539
2/1/53	Cascade	UF_6	300	93.5	280	19	2.0E-02	Purge cascade calculations	ESA	3189
3/1/53	Cascade	UF_6	1647	93.5	1540	107	1.1E-01	Purge cascade calculations	ESA	3189
3/30/53	K-1401	UF_6	29913	1.2	353	29560	2.6E-02	Recovered uranium from furnace fluorination of 59 converters and 2 compressors were vented to atmosphere over a three month period	ESA	631, 2470, 2539
4/1/53	Cascade	UF_6	752	93.5	703	49	4.9E-02	Purge cascade calculations	ESA	3189
4/15/53	K-631	UF_6	1534	0.65	10	1524	9.9E-04	Bearing failure on compressor	EIVA	652, 2539
5/1/53	K-631	UF_6	15243	0.6	98	15145	9.8E-03	Blank-off plate on a pump discharge line blew off	EIVA	652, 631, 2470, 2539
5/1/53	Cascade	UF_6	736	93.5	688	48	4.8E-02	Purge cascade calculations	ESA	3189
5/10/53	K-633	UF_6	6133	0.4	25	6108	3.4E-03	Overloaded alumina trap vent to atmosphere	ESA	652
5/25/53	K-413	UF_6	83197	0.7	592	82605	5.6E-02	Cylinder exploded; oil and UF6 mixture	CIVA	652, 2470, 2320, 2539

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
6/1/53	K-1131	UF_6	269134	0.7	1790	267344	1.8E-01	Upper part of valve blown from body from a 1 ton cylinder - release escaped building and cloud drifted across site causing other buildings to be evacuated	CIVA	652, 631, 2470, 2539
6/1/53	Cascade	UF_6	368	93.5	344	24	2.4E-02	Purge cascade calculations	ESA	3189
6/4/53	K-1004-A rm 19	UF_6	3	0.711	0.02	3	1.8E-06	tube	EIVA	2886
6/30/53	K-1401	UF_6	12630	2.1	262	12368	1.5E-02	Recovered uranium from furnace fluorination of 45 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
7/1/53	Cascade	UF_6	156	93.5	145	10	1.0E-02	Purge cascade calculations	ESA	3189
8/1/53	Cascade	UF_6	88	93.5	82	6	5.8E-03	Purge cascade calculations	ESA	3189
8/2/53	K-413	UF_6	5000	0.8	40	4960	3.5E-03	Release when alumina traps opened	EIVA	652, 2470, 2539
8/13/53	K-1131	UF_6	300	0.7	2	298	2.0E-04	Powder seal failed on the F2 scrubber	EIVA	2470, 2539
8/31/53	K-1004-C rm 207	UF_6	20	0.711	0.1	20	1.4E-05	cold trap broke	EIVA	2886
9/1/53	Cascade	UF_6	213	93.5	199	14	1.4E-02	Purge cascade calculations	ESA	3189
9/6/53	K-402-4	UF_6	3067	0.71	22	3045	2.1E-03	Cylinder valve failure	CIVA	652, 2470, 2539
9/7/53	K-131	UF_6	3067	1.21	37	3030	2.7E-03	Cylinder valve broke	CIVA	652, 2539
9/9/53	K-1401	UF_6	5521	0.9	50	5471	4.1E-03	Plugged line caused cylinder rupture	CIVA	652, 631, 2470, 2539
9/30/53	K-1401	UF_6	3512	1.9	66	3446	4.0E-03	Recovered uranium from furnace fluorination of 15 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
9/30/53	K-402-8	UF_6	29730	0.9	262	29468	2.2E-02	Cold trap heated up and vaporized UF6 - operational error caused material to be blown to the atmosphere	EIVA	652, 2470, 2539

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
10/1/53	Cascade	UF_6	210	93.5	196	14	1.4E-02	Purge cascade calculations	ESA	3189
10/30/53	K-1131	UF_6	15336	0.7	103	15233	1.0E-02	Cold trap warmed up vaporizing Hanford waste	EIVA	652, 631, 2470, 2539
11/1/53	Cascade	UF_6	106	93.5	99	7	7.0E-03	Purge cascade calculations	ESA	3189
11/20/53	K-633 Test Loop	UF_6	613	0.6	4	609	3.9E-04	operator error	ESA	2886
12/1/53	Cascade	UF_6	62	93.5	58	4	4.1E-03	Purge cascade calculations	ESA	3189
12/19/53	K-1131	UF_6	3067	0.71	22	3045	2.1E-03	Burned gasket on pigtail	CIVA	652, 2539
12/22/53	K-1131	UF_6	2147	0.71	15	2132	1.4E-03	Overpressure in F2 scrubber	EIVA	652, 2539
12/29/53	K-101	UF_6	3067	21.6	663	2404	3.1E-02	Broken sight glass	EIVA	652, 2539
12/31/53	K-1401	UF_6	1330	2.0	26	1304	1.5E-03	Recovered uranium from furnace fluorination of 13 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
1/1/54	Cascade	UF_6	321	93.5	300	21	2.1E-02	Purge cascade calculations	ESA	3189
2/1/54	Cascade	UF_6	842	93.5	788	55	5.5E-02	Purge cascade calculations	ESA	3189
2/12/54	K-131	UF_6	1534	1.8	28	1506	1.7E-03	Pressure control valve ruptured	EIVA	652, 2539
3/1/54	Cascade	UF_6	430	93.5	402	28	2.8E-02	Purge cascade calculations	ESA	3189
3/30/54	K-1401	UF_6	8325	3.6	303	8022	1.5E-02	Recovered uranium from furnace fluorination of 21 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
4/1/54	Cascade	UF_6	322	93.5	301	21	2.1E-02	Purge cascade calculations	ESA	3189
5/1/54	Cascade	UF_6	574	93.5	537	37	3.8E-02	Purge cascade calculations	ESA	3189
5/20/54	K-1004-D	UF_6	135	0.7115	1	134	9.1E-05	Cold trap broke releasing its contents	EIVA	631, 2470
5/30/54	K-1401	UF_6	1000	0.7115	7	993	6.7E-04	Faulty valve caused release in the pilot plant	EIVA	652, 631, 2470, 2539
6/1/54	Cascade	UF_6	260	93.5	243	17	1.7E-02	Purge cascade calculations	ESA	3189
6/11/54	K-306-7	UF_6	10	90	9	1	6.2E-04	Escaped through the product drain line valve in the Product Purification Unit	EIVA	631, 2470, 2539

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
6/21/54	K-633	UF_6	15336	0.7	101	15235	1.0E-02	Plug in cylinder valve caused pigtail to disconnect	CIVA	652, 631, 2470, 2539
6/29/54	K-1004-A	UF_6	50	93.2	47	3	3.3E-03	Thermowell weld released sample cylinder contents to the hood	CIVA	631, 2470, 2539
6/30/54	K-306-7	UF_6	128	93.2	119	9	8.4E-03	Thermowell weld released sample line contents	EIVA	631, 2470, 2539
7/1/54	Cascade	UF_6	1161	93.5	1086	75	7.6E-02	Purge cascade calculations	ESA	3189
8/1/54	Cascade	UF_6	1500	93.5	1403	98	9.8E-02	Purge cascade calculations	ESA	3189
8/2/54	K-1401	UF_6	500	0.7115	4	496	3.4E-04	Failure in the feed line of the pilot plant	EIVA	631, 2470, 2539
8/30/54	K-631	UF_6	3067	0.71	22	3045	2.1E-03	Ruptured flexible connection while replacing contaminated oil in a pump	EIVA	652, 631, 2470, 2539
9/1/54	Cascade	UF_6	3285	93.5	3071	214	2.2E-01	Purge cascade calculations	ESA	3189
9/30/54	K-1401	UF_6	10855	2.9	315	10540	1.7E-02	Recovered uranium from furnace fluorination of 26 converters were vented to atmosphere over a six month period	ESA	631, 2470, 2539
10/1/54	Cascade	UF_6	1606	93.5	1502	104	1.1E-01	Purge cascade calculations	ESA	3189
10/10/54	K-1004-L	UF_6	3067	0.7	20	3047	2.0E-03	Defective seal in pilot plant leaked	EIVA	652, 631, 2470, 2539
10/14/54	K-306-7	UF_6	46	93.5	43	3	3.0E-03	Cylinder valve failure on the product withdrawal manifold	CIVA	631, 2470, 2539
11/1/54	K-1131	UF_6	22415	0.7	150	22265	1.5E-02	Monthly stack vent - periodic sampling	ESA	631, 2442, 2470, 2539
11/1/54	Cascade	UF_6	266	93.5	248	17	1.7E-02	Purge cascade calculations	ESA	3189
12/1/54	Cascade	UF_6	98	93.5	91	6	6.4E-03	Purge cascade calculations	ESA	3189
12/13/54	K-306-7	UF_6	34	94.1	32	2	2.3E-03	Rupture in valve bellows in a freeze-out line in the product purification unit	EIVA	2470, 2539
12/22/54	K-413	UF_6	3067	1.3	40	3027	2.8E-03	Leaked from Beach-Russ pump	EIVA	652, 631, 2470, 2539

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
12/31/54	K-1401	UF_6	815	4.9	40	775	1.9E-03	Recovered uranium from furnace fluorination of 5 converters were vented to atmosphere over a three month period	ESA	631, 2470, 2539
1/1/55	Cascade	UF_6	46	93.5	43	3	3.0E-03	Purge cascade calculations	ESA	3189
1/21/55	K-306-7	UF_6	28	92.9	26	2	1.8E-03	Rupture in valve bellows in a freeze-out line in the product purification unit	EIVA	2470
2/1/55	Cascade	UF_6	139	93.5	130	9	9.1E-03	Purge cascade calculations	ESA	3189
3/1/55	K-306-9	UF_6	28	93.5	26	2	1.8E-03	Rupture of bellows of drain valve.	EIVA	631
3/1/55	Cascade	UF_6	54	93.5	51	4	3.6E-03	Purge cascade calculations	ESA	3189
3/10/55	K-33	UF_6	144815	0.71	1028	143787	9.7E-02	Cylinder and pigtail explosion and rupture	CIVA	652, 631, 2470
3/16/55	K-631	UF_6	3012	0.5	15	2997	1.8E-03	Seal failure on Elliott compressor	EIVA	652, 631, 2470
3/30/55	K-1401	UF_6	2988	2.7	82	2906	4.4E-03	Recovered uranium from furnace fluorination of 24 converters were vented to atmosphere over a three month period	ESA	631, 2470
4/1/55	Vaults	UF_6	30365	0.71	216	30149	2.0E-02	Rupture in feed cylinders due to overheating.	CIVA	631
4/1/55	Cascade	UF_6	72	93.5	67	5	4.7E-03	Purge cascade calculations	ESA	3189
4/19/55	K-633	UF_6	7668	0.4	31	7637	4.2E-03	Copper tubing pigtail ruptured	CIVA	652, 2322, 2539
5/1/55	Cascade	UF_6	10	93.5	9	0.7	6.7E-04	Purge cascade calculations	ESA	3189
6/1/55	Cascade	UF_6	69	93.5	64	4	4.5E-03	Purge cascade calculations	ESA	3189
7/1/55	K-1401	UF_6	1135	5.4	61	1074	2.9E-03	Vented to atmosphere.	ESA	631, 2322, 2539
7/1/55	K-1131	UF_6	3555	0.7	24	3531	2.3E-03	Vented to atmosphere.	ESA	631, 2442, 2322, 2539
7/1/55	Development	UF_6	7668	0.711	55	7613	5.2E-03	Rupture in copper tubing pigtail connected to feed cylinder.	CIVA	631

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
7/1/55	Cascade	UF_6	83	93.5	78	5	5.5E-03	Purge cascade calculations	ESA	3189
8/1/55	K-1131	UF_6	6297	0.7	42	6255	4.1E-03	Vented to atmosphere.	ESA	631, 2322, 2539
8/1/55	Cascade	UF_6	128	93.5	120	8	8.4E-03	Purge cascade calculations	ESA	3189
8/31/55	K-301-1	UF_6	153	15.0	23	130	1.1E-03	Mis-valving during cell purge and evacuation	EIVA	2322, 2539
9/1/55	K-1131	UF_6	11130	0.7	75	11055	7.3E-03	Vented to atmosphere.	ESA	631, 2322, 2539
9/1/55	Cascade	UF_6	122	93.5	114	8	8.0E-03	Purge cascade calculations	ESA	3189
10/1/55	K-1401	UF_6	120	1.7	2	118	1.3E-04	Lost to atmosphere.	ESA	631, 2322, 2539
10/1/55	K-1131	UF_6	10406	0.7	70	10336	6.8E-03	Vent stack release.	ESA	631, 2322, 2539
10/1/55	Cascade	UF_6	158	93.5	148	10	1.0E-02	Purge cascade calculations	ESA	3189
10/13/55	K-1401	UF_6	24	4.2	1	23	4.9E-05	Sample tube ruptured	EIVA	2539
10/30/55	K-33	UF_6	1840	0.8	14	1826	1.3E-03	Cylinder valve leak	CIVA	652, 631, 2322, 2539
11/1/55	K-1131	UF_6	14211	0.7	95	14116	9.3E-03	Vented to atmosphere.	ESA	631, 2322, 2539
11/1/55	Cascade	UF_6	58	93.5	54	4	3.8E-03	Purge cascade calculations	ESA	3189
11/8/55	K-1131	UF_6	3067	0.7	21	3046	2.0E-03	Plugged line caused pressure blow back to tower	EIVA	652, 2322, 2539
12/1/55	K-1131	UF_6	16202	0.7	109	16093	1.1E-02	Vented to atmosphere.	ESA	631, 2322, 2539
12/1/55	Cascade	UF_6	37	93.5	35	2	2.4E-03	Purge cascade calculations	ESA	3189
12/4/55	K-306-7	UF_6	100	93	93	7	6.5E-03	Rupture of bellows drain line valve	EIVA	631, 2322, 2539
12/26/55	K-413	UF_6	2147	1.5	32	2115	2.1E-03	Cylinder valve leak	CIVA	652, 631. 2322, 2539
1/1/56	K-1131	UF_6	3067	0.6	18	3049	1.9E-03	Leak in clean-up reactor.	EIVA	631
1/1/56	K-1131	UF_6	12471	0.5	66	12405	7.5E-03	Vented to atmosphere.	ESA	631, 2322

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
1/20/56	K-33 Feed	UF_6	1534	0.8	12	1522	1.1E-03	Leak at valve threads on feed cylinder	CIVA	652, 2322
2/1/56	K-1131	UF_6	14410	0.7	97	14313	9.5E-03	Vented to atmosphere.	ESA	631, 2322
3/1/56	K-1131	UF_6	11980	0.7	80	11900	7.9E-03	Vented to atmosphere.	ESA	631, 2322
4/1/56	K-1131	UF_6	10070	0.7	70	10000	6.7E-03	Vented to atmosphere.	ESA	631, 2322, 2539
5/1/56	K-1131	UF_6	8900	0.7	60	8840	5.9E-03	Vented to atmosphere.	ESA	631, 2322, 2539
5/6/56	K-633	UF_6	1534	0.3	5	1529	8.1E-04	Blown gasket in test loop	EIVA	652, 2442, 2539
6/1/56	K-1131	UF_6	51014	0.7	342	50672	3.3E-02	Monthly stack vent - periodic sampling	ESA	631, 2442, 2539
6/13/56	K-303	UF_6	1534	0.3	5	1529	8.1E-04	Leaking valve.	EIVA	652, 631
7/1/56	K-1131	UF_6	15974	0.7	106	15868	1.0E-02	Monthly stack vent - periodic sampling	ESA	631, 2442
8/1/56	K-1131	UF_6	17189	0.6	95	17094	1.1E-02	Monthly stack vent - periodic sampling	ESA	631, 2442
8/15/56	K-1131	UF_6	30672	0.3	92	30580	1.6E-02	normal vent emissions from stack	ESA	2892
8/31/56	K-1131	UF_6	30672	0.3	92	30580	1.6E-02	Gasket on UF6 pump failed and material vented to atmosphere	ESA	652, 2442
9/1/56	K-1131	UF_6	18594	0.5	93	18501	1.1E-02	Monthly stack vent - periodic sampling	ESA	2442
9/9/56	K-1004-L	UF_6	3066	0.7	20	3046	2.0E-03	Cylinder connection failed	CIVA	652, 2442
9/20/56	K-601	UF_6	4673	0.71	33	4640	3.1E-03	Rupture disk blown out	EIVA	652, 2442
10/1/56	K-1024	UF_6	224	0.6	1	223	1.4E-04	Rupture of a diaphragm	EIVA	2442
10/1/56	K-1131	UF_6	7036	0.7	47	6989	4.6E-03	Monthly stack vent - periodic sampling	ESA	2442
11/1/56	K-1131	UF_6	4439	0.7	30	4409	2.9E-03	Monthly stack vent - periodic sampling	ESA	2442
12/1/56	K-1131	UF_6	14148	0.7	95	14053	9.3E-03	Monthly stack vent - periodic sampling	ESA	2442

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
1/1/57	K-1131	UF_6	10041	0.7	67	9974	6.6E-03	Monthly stack vent - periodic sampling	ESA	2442
1/7/57	K-1131	UF_6	1840	0.7	12	1828	1.2E-03	Powder seal failure	EIVA	652. 2442
2/1/57	K-1131	UF_6	11336	0.7	76	11260	7.4E-03	Monthly stack vent - periodic sampling	ESA	2442
2/22/57	K-1131	UF_6	1534	0.7	10	1524	9.9E-04	Faulty cylinder valve	CIVA	652. 2442
3/1/57	K-1131	UF_6	26545	0.4	111	26434	1.5E-02	Monthly stack vent - periodic sampling	ESA	2442
4/1/57	K-1131	UF_6	34451	0.3	120	34331	1.8E-02	Monthly stack vent - periodic sampling	ESA	2442
5/1/57	K-1131	UF_6	35098	0.7	231	34867	2.3E-02	Monthly stack vent - periodic sampling	ESA	2442
6/1/57	K-1131	UF_6	54547	0.7	381	54166	3.6E-02	Monthly stack vent - periodic sampling	ESA	2442
7/1/57	K-1131	UF_6	47429	0.7	320	47109	3.1E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
8/1/57	K-304-5	UF_6	253	72.3	183	70	1.2E-02	Material released during pressure test of a cell	EIVA	2539
8/1/57	K-1131	UF_6	20651	0.7	140	20511	1.4E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
9/1/57	K-1131	UF_6	5079	0.7	34	5045	3.3E-03	Monthly stack vent - periodic sampling	ESA	2442, 2539
10/1/57	K-1131	UF_6	14740	0.7	103	14637	9.7E-03	Monthly stack vent - periodic sampling	ESA	2442, 2539
10/10/57	K-413	UF_6	3041	1.5	46	2995	3.0E-03	Copper tube burned from a reaction in oil mist filter	EIVA	652, 2442, 2539
11/1/57	K-1131	UF_6	23409	0.7115	167	23242	1.6E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
11/26/57	K-631	UF_6	307	0.4	1	306	1.7E-04	Drain line ruptured	EIVA	2442, 2539
12/1/57	K-1131	UF_6	18588	0.7	126	18462	1.2E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
1/1/58	Vault	UF_6	3041	0.7	20	3021	2.0E-03	Hole burned in mist filter	CIVA	652

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
1/1/58	K-1131	UF_6	36147	0.7115	257	35890	2.4E-02	Monthly stack vent - periodic sampling	ESA	2442
1/12/58	K-33	UF_6	4600	0.71	33	4567	3.1E-03	Faulty pigtail connection	EIVA	652, 2442
1/13/58	K-902.4	UF_6	307	1.3	4	303	2.8E-04		EIVA	2892
1/25/58	K-631	UF_6	4600	0.4	18	4582	2.5E-03	Valve bellows rupture	EIVA	652, 2442
2/1/58	K-1131	UF_6	30752	0.7	215	30537	2.1E-02	Monthly stack vent - periodic sampling	ESA	2442
2/9/58	K-631	UF_6	1533	0.4	6	1527	8.5E-04	Faulty pigtail connection	CIVA	652
2/25/58	K-1401	UF_6	31	0.711	0.2	30	2.1E-05		ESA	2961
3/1/58	K-1131	UF_6	20811	0.7115	148	20663	1.4E-02	Monthly stack vent - periodic sampling	ESA	2442
3/5/58	K-1401	UF_6	15	0.711	0.1	15	1.0E-05		ESA	2961
3/13/58	K-1401	UF_6	31	0.711	0.2	30	2.1E-05		ESA	2961
3/20/58	K-33	UF_6	22080	0.71	157	21923	1.5E-02	Cylinder valve failure	CIVA	652
3/21/58	K-1401	UF_6	6	0.711	0.04	6	4.1E-06		ESA	2961
4/1/58	Vault	UF_6	4601	0.7	30	4571	3.0E-03	Valve bellows rupture	EIVA	652
4/1/58	K-1131	UF_6	25087	0.7	176	24911	1.7E-02	Monthly stack vent - periodic sampling	ESA	2442
5/1/58	K-1131	UF_6	24329	0.7	166	24163	1.6E-02	Monthly stack vent - periodic sampling	ESA	2442
5/8/58	K-1401	UF_6	61	0.711	0.4	61	4.1E-05		ESA	2961
6/1/58	K-1131	UF_6	19771	0.7	137	19634	1.3E-02	Monthly stack vent - periodic sampling	ESA	2442
6/25/58	K-402-3.6	UF_6	205	10.2	21	184	9.5E-04	Line recorder line opened, due to wear, inside cell	EIVA	2892
7/1/58	K-1131	UF_6	40527	0.7	288	40239	2.7E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
8/1/58	K-1131	UF_6	58854	0.7	407	58447	3.9E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
9/1/58	K-1131	UF_6	54326	0.7115	387	53939	3.7E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
9/1/58	K-1131	UF_6	799679	0.71	5678	794001	5.4E-01	Ruptured filter in hydrogen reduction system	EIVA	652
9/2/58	K-1004-L	UF_6	7666	0.7	51	7615	5.0E-03	Purge compressor seal failed	EIVA	652, 2442, 2539
9/3/58	K-631	UF_6	307	0.3	1	306	1.6E-04	Cylinder valve leaked	CIVA	2442, 2539
9/5/58	K-1131	UF_6	374212	0.71	2657	371555	2.5E-01	Loss in transferring material	EIVA	652
9/11/58	K-1004-A	UF_6	705	0.4	3	702	4.0E-04	Faulty sample connection	CIVA	652, 2442, 2539
10/1/58	K-1131	UF_6	31109	0.7	217	30892	2.1E-02	Monthly stack vent - periodic sampling	ESA	2442
10/15/58	K-1401	UF_6	307	0.711	2	304	2.1E-04		ESA	2961
11/1/58	K-1131	UF_6	25794	0.7	182	25612	1.7E-02	Monthly stack vent - periodic sampling	ESA	2442
12/1/58	K-1131	UF_6	31034	0.7	221	30813	2.1E-02	Monthly stack vent - periodic sampling	ESA	2442
1/1/59	K-1131	UF_6	46907	0.7	312	46595	3.1E-02	Monthly stack vent - periodic sampling	ESA	2442
1/19/59	K-1413	UF_6	460	0.711	3	457	3.1E-04		ESA	2960
2/1/59	K-1131	UF_6	45818	0.7	317	45501	3.0E-02	Monthly stack vent - periodic sampling	ESA	2442
2/16/59	K-312-1	UF_6	7	100	7	0	5.1E-04	Pump stalled causing leakage around gland	EIVA	1441, 2442
2/16/59	K-312-1	UF_6	13	92.3	12	1	8.4E-04	Alumina trap overload resulting in purge to vent stack	ESA	1441, 2442
2/27/59	K-1420	UF_6	2819	0.67	19	2800	1.8E-03	Corroded base caused pump flange failure	EIVA	652, 2442
3/1/59	K-1131	UF_6	42021	0.7	298	41723	2.8E-02	Monthly stack vent - periodic sampling	ESA	2442
3/8/59	K-1413	UF_6	307	0.711	2	304	2.1E-04		ESA	2960
4/1/59	K-1131	UF_6	28406	0.8	222	28184	2.0E-02	Monthly stack vent - periodic sampling	ESA	2442
4/3/59	K-304-2	Solution	6400	60	3840	2560	2.3E-01	Drain line leak	EIVA	652

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
5/1/59	K-1131	UF_6	62668	0.7	427	62241	4.1E-02	Monthly stack vent - periodic sampling	ESA	2442
6/1/59	K-1131	UF_6	58239	0.7	422	57817	3.9E-02	Monthly stack vent - periodic sampling	ESA	2442
7/1/59	K-1131	UF_6	57042	0.7	426	56616	3.9E-02	Monthly stack vent - periodic sampling	ESA	2442
8/1/59	K-1131	UF_6	30818	0.7	211	30607	2.0E-02	Monthly stack vent - periodic sampling	ESA	2442
9/1/59	K-1131	UF_6	41317	0.7	301	41016	2.8E-02	Monthly stack vent - periodic sampling	ESA	2442
10/1/59	K-1131	UF_6	33180	0.7115	236	32944	2.2E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
10/18/59	K-1401	UF_6	31	0.711	0.2	30	2.1E-05		ESA	2960
10/26/59	K-1413	UF_6	307	0.711	2	304	2.1E-04		ESA	2960
11/1/59	K-1131	UF_6	38207	0.7	271	37936	2.6E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
11/11/59	K-1413	UF_6	71	0.711	0.5	70	4.7E-05		ESA	2960
12/1/59	K-1131	UF_6	46749	0.7	327	46422	3.1E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
12/24/59	K-305-7	UF_6	10	93.5	9	0.6	6.6E-04	Feed tube rupture	EIVA	1441
1/1/60	K-1131	UF_6	47460	0.7	343	47117	3.2E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
2/1/60	K-1131	UF_6	51153	0.7	355	50798	3.4E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
2/13/60	K-33	UF_6	613	0.711	4	609	4.1E-04	Cylinder valve struck while moving and began leaking	CIVA	1441
2/24/60	K-1131	UF_6	214960	0.7	1528	213418	1.4E-01	ruptured heating coil in "E" cold trap	EIVA	2886
2/27/60	K-1131	UF_6	460008	0.7	3174	456834	3.1E-01	Ruptured tube in cold trap	EIVA	652, 1441
2/29/60	K-631	UF_6	38894	0.71	276	38618	2.6E-02	Cylinder valve leaked	CIVA	652, 2539
3/1/60	K-1420	UF_6	27992	1.5	414	27578	2.7E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
3/1/60	K-1131	UF_6	38894	0.7	277	38617	2.6E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
4/1/60	K-1420	UF_6	408	1.5	6	402	3.9E-04	Monthly stack vent - periodic sampling	ESA	2442
4/1/60	K-1131	UF_6	42375	0.7	301	42074	2.8E-02	Monthly stack vent - periodic sampling	ESA	2442
5/1/60	K-1420	UF_6	1889	1.5	28	1861	1.8E-03	Monthly stack vent - periodic sampling	ESA	2442
5/1/60	K-1131	UF_6	46255	0.7	321	45934	3.1E-02	Monthly stack vent - periodic sampling	ESA	2442
5/7/60	K-1131	UF_6	184003	0.6	1196	182797	1.2E-01	rupture of steam heating coil during drainage of the "F" cold trap	EIVA	2886
6/1/60	K-1420	UF_6	863	1.5	13	850	8.4E-04	Monthly stack vent - periodic sampling	ESA	2442
6/1/60	K-1131	UF_6	60662	0.7	415	60247	4.0E-02	Monthly stack vent - periodic sampling	ESA	2442
6/9/60	K-1420	UF_6	2017	0.6	13	2004	1.3E-03	Drain line plugged and released material	EIVA	652, 1441, 2442
7/1/60	K-1420	UF_6	89	1.5	1	88	8.7E-05	Monthly stack vent - periodic sampling	ESA	2442
7/1/60	K-1131	UF_6	51532	0.7	367	51165	3.5E-02	Monthly stack vent - periodic sampling	ESA	2442
8/1/60	K-1420	UF_6	313	1.3	4	309	2.8E-04	Monthly stack vent - periodic sampling	ESA	2442
8/1/60	K-1131	UF_6	30238	0.7	203	30035	2.0E-02	Monthly stack vent - periodic sampling	ESA	2442
9/1/60	K-1131	UF_6	103030	0.7	695	102335	6.8E-02	Monthly stack vent - periodic sampling	ESA	2442
10/1/60	K-1131	UF_6	11881	0.7115	84	11797	8.0E-03	Monthly stack vent - periodic sampling	ESA	2442
10/20/60	K-631	UF_6	1534	0.4	6	1528	8.4E-04	Bellows ruptured on drain line	EIVA	1441, 2442
11/1/60	K-1420	UF_6	43	75	35	8	2.1E-03	Monthly stack vent - periodic sampling	ESA	2442

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
11/1/60	K-1131	UF_6	19286	0.7115	137	19149	1.3E-02	Monthly stack vent - periodic sampling	ESA	2442
12/1/60	K-1420	UF_6	337	14.5	49	288	2.2E-03	Monthly stack vent - periodic sampling	ESA	2442
12/1/60	K-1131	UF_6	37161	0.8	305	36856	2.7E-02	Monthly stack vent - periodic sampling	ESA	2442
1/2/61	K-631	UF_6	1533	0.4	6	1527	8.4E-04	Leaking pigtail gasket	CIVA	652, 1441, 2442, 2539
1/25/61	K-31	UF_6	676	0.4	3	673	3.8E-04	Radiation monitor testing	ESA	2442, 2539
2/1/61	K-1420	UF_6	841	1.5	12	829	8.1E-04	Monthly stack vent - periodic sampling	ESA	2442, 2539
2/1/61	K-1131	UF_6	20155	0.8	152	20003	1.4E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
2/1/61	K-1131	UF_6	65072	0.7	477	64595	4.4E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
3/1/61	K-1420	UF_6	297	1.5	4	293	2.9E-04	Monthly stack vent - periodic sampling	ESA	2442, 2539
3/1/61	K-1131	UF_6	29317	0.8	239	29078	2.1E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
3/1/61	Cascade	UF_6	53	93.5	49	3	3.4E-03	Purge cascade calculations	ESA	3189
3/2/61	K-413	UF_6	920	1.2	11	909	7.9E-04	Leak in gasket of sight glass	EIVA	1441, 2442, 2539
3/31/61	K-1131	UF_6	3067	0.71	22	3045	2.1E-03	Cold trap draining valve packing failed	EIVA	652, 1441, 2442, 2539
4/1/61	K-1004-L	Lab Waste	200	1.5	3	197	2.0E-04	Glass traps ruptured	EIVA	2442, 2539
4/1/61	K-1420	UF_6	2171	1.5	33	2138	2.1E-03	Monthly stack vent - periodic sampling	ESA	2442, 2539
4/1/61	K-1131	UF_6	64842	0.8	491	64351	4.5E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
4/1/61	Cascade	UF_6	55	93.5	51	4	3.6E-03	Purge cascade calculations	ESA	3189

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
5/1/61	K-1420	UF_6	1396	1.5	21	1375	1.4E-03	Monthly stack vent - periodic sampling	ESA	2442, 2539
5/1/61	K-1131	UF_6	87280	0.8	658	86622	6.0E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
5/1/61	Cascade	UF_6	90	93.5	84	6	5.9E-03	Purge cascade calculations	ESA	3189
5/10/61	K1004-A	UF_6	1152	0.7	8	1144	7.7E-04	Valve bonnet broke off sample bottle and material exhausted through hood roof vents to atmosphere	CSA	652, 1441, 2442, 2539
5/13/61	K-1131	UF_6	92015	0.6	598	91417	6.0E-02	Secondary cold trap tube rupture	EIVA	652, 242, 2539
5/19/61	K-1131	UF_6	6134	0.7	40	6094	4.0E-03	While attempting to locate cold trap plugs, material was allowed to go to vent stack. The K-402-6 and K-402-7 ventilation fans were pulling air and caused the K-1131 vent stack to flow through the two K-402 units.	ESA	652, 1441, 2442, 2539
5/23/61	K-1004-J	Lab Waste	350	1.5	5	345	3.4E-04	Glass trap ruptured	EIVA	2442, 2539
6/1/61	K-1420	UF_6	738	3.7	27	711	1.4E-03	Monthly stack vent - periodic sampling	ESA	2442, 2539
6/1/61	K-1131	UF_6	89967	0.7	613	89354	5.9E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
6/1/61	Cascade	UF_6	47	93.5	44	3	3.1E-03	Purge cascade calculations	ESA	3189
6/3/61	K-33	UF_6	1840	1.6	29	1811	1.9E-03	Misvalving during cylinder evacuation caused release	CIVA	652, 1441, 2442, 2539
7/1/61	K-1420	UF_6	907	3.9	35	872	1.8E-03	Monthly stack vent - periodic sampling	ESA	2442, 2539
7/1/61	K-1131	UF_6	23308	0.8	190	23118	1.7E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
7/1/61	Cascade	UF_6	90	93.5	84	6	5.9E-03	Purge cascade calculations	ESA	3189
7/19/61	K-902-4	UF_6	135	0.711	1	134	9.1E-05	Cut into a line that had been purged	EIVA	1441
7/26/61	K-1131	UF_6	6133	0.6	37	6096	3.9E-03	Cracked pigtail on cold trap	EIVA	652, 1441

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
8/1/61	K-1420	UF_6	582	3.15	18	564	9.5E-04	Monthly stack vent - periodic sampling	ESA	2442, 2539
8/1/61	K-1131	UF_6	41324	0.8	330	40994	2.9E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
8/1/61	Cascade	UF_6	299	93.5	279	19	2.0E-02	Purge cascade calculations	ESA	3189
9/1/61	K-1420	UF_6	31	2.8	0.9	30	4.7E-05	Monthly stack vent - periodic sampling	ESA	2442, 2539
9/1/61	K-1131	UF_6	24347	0.9	224	24123	1.8E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
9/1/61	Cascade	UF_6	154	93.5	144	10	1.0E-02	Purge cascade calculations	ESA	3189
9/29/61	K-1131	UF_6	1533	0.71	11	1522	1.0E-03	Jet assembly burnt out on reactor	EIVA	652, 1441
10/1/61	K-1420	UF_6	20	6.9	1	19	6.4E-05	Monthly stack vent - periodic sampling	ESA	2442, 2539
10/1/61	K-1131	UF_6	19363	0.92	178	19185	1.5E-02	Monthly stack vent - periodic sampling	ESA	2442, 2539
10/1/61	Cascade	UF_6	346	93.5	323	22	2.3E-02	Purge cascade calculations	ESA	3189
11/1/61	K-1420	UF_6	120	7.0	8	112	3.9E-04	Monthly stack vent - periodic sampling	ESA	2442, 2539
11/1/61	Cascade	UF_6	196	93.5	183	13	1.3E-02	Purge cascade calculations	ESA	3189
11/13/61	K-1413	UF_6	193203	0.2	431	192772	9.4E-02	Cylinder valve packing gland failed and material released	CIVA	652, 1441, 2442, 2539
12/1/61	K-1420	UF_6	63	6.2	4	59	1.8E-04	Monthly stack vent - periodic sampling	ESA	2442, 2539
12/1/61	Cascade	UF_6	217	93.5	203	14	1.4E-02	Purge cascade calculations	ESA	3189
1/1/62	K-1420	UF_6	112	7.9	9	103	4.1E-04	Monthly stack vent - periodic sampling	ESA	3189
2/1/62	K-1420	UF_6	245	15.7	38	207	1.8E-03	Monthly stack vent - periodic sampling	ESA	2442
3/1/62	K-1420	UF_6	187	37.4	70	117	3.6E-03	Monthly stack vent - periodic sampling	ESA	2442
3/1/62	K-1413	UF_6	19933	0.6	120	19813	1.3E-02	Ruptured copper tubing	EIVA	652, 1441

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
3/2/62	K-1413	UF_6	3681	0.2	8	3673	1.8E-03	Ruptured process line	EIVA	952, 1441, 2442, 2539
3/16/62	K-1420	U3O8 and UF_6	6078	40.97	2490	3588	1.3E-01	Cold trap valve failure	EIVA	652, 1441, 2442
5/1/62	K-1420	UF_6	234	1.3	3	234	2.1E-04	Monthly stack vent - periodic sampling	ESA	2442, 2539
6/1/62	K-1420	UF_6	51	1.3	0.7	50	4.6E-05	Monthly stack vent - periodic sampling	ESA	2442
7/1/62	K-1420	UF_6	10	1.36	0.1	10	9.2E-06	Monthly stack vent - periodic sampling	ESA	2442
8/1/62	K-1420	UF_6	6628	1.34	90	6538	6.1E-03	Monthly stack vent - periodic sampling	ESA	2442
9/23/62	K-1006	UF_6	307	0.6	2	305	1.9E-04	Bellows rupture on pump circulating gas in the laboratory high temperature test loop.	EIVA	1441
10/1/62	K-1420	UF_6	168	1.5	3	165	1.6E-04	Monthly stack vent - periodic sampling	ESA	2442
11/1/62	K-1420	UF_6	5411	1.9	103	5308	6.1E-03	Monthly stack vent - periodic sampling	ESA	2442
12/1/62	K-1420	UF_6	5834	3	175	5659	9.2E-03	Monthly stack vent - periodic sampling	ESA	2442
1/1/63	K-1420	UF_6	11	5.8	0.6	10	3.0E-05	Monthly stack vent - continuous sampling	ESA	2442, 2539
2/1/63	K-1420	UF_6	20	27.6	6	14	2.7E-04	Monthly stack vent - continuous sampling	ESA	2442, 2539
3/1/63	K-1420	UF_6	36	19.4	7	29	3.3E-04	Monthly stack vent - continuous sampling	ESA	2442, 2539
3/25/63	K-1004-A	UF_6	270	7.4	20	250	9.2E-04	Sample tube ruptured releasing material to hood	CSA	1441, 2442
4/1/63	K-1420	UF_6	27	3.3	0.9	26	4.6E-05	Monthly stack vent - periodic sampling	ESA	2442
11/20/63	K-31	UF_6	613	0.711	4	609	4.1E-04	Release from feed cylinder pigtail	CIVA	1441

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
1/22/64	K-1420	UF_6	613	2.8	17	596	9.1E-04	Pigtail plugged during cold trap draining	EIVA	2442
3/1/64	K-1420	UF_6	153	33	50	103	2.5E-03	Quarterly stack vent - continuous sampling	ESA	2442
3/2/64	K-1131	UF_6	3067	0.36	11	3056	1.6E-03	Bad gasket on pigtail connection	CIVA	952, 1441, 2442
3/23/64	K-1420	UF_6	30	56.7	17	13	9.9E-04	Plug in cold trap inlet line	EIVA	2442
4/18/64	K-33	UF_6	294	0.711	2	292	2.0E-04	Small leakage in cylinder valve during feed operation	CIVA	1441
10/18/64	K-1131	UF_6	613	0.2	1	612	2.8E-04	Disconnection of pigtail from cylinder	CIVA	1441, 2539
7/13/65	K-1401	UF_6	23611	5	1181	22430	5.6E-02	Weld crack on a cylinder seam	CIVA	1441
11/23/65	K-631	UF_6	4600	0.4	18	4582	2.5E-03	Bellows rupture on transmitter	EIVA	952, 1441
11/29/65	K-311-1	UF_6	613	5	31	582	1.5E-03	Difficulty experienced in the hi-speed purge equipment resulted in a discharge of a small quantity of UF6 through the stack to atmosphere.	ESA	1441
9/1/66	K-1004-A	UF_6	560	2.6	15	545	7.9E-04	Diaphragm ruptured when the bonnet of the valve was removed to inspect a possible plugged valve.	EIVA	1441, 2539
1/1/68	N/A	UF_6	1589	0.3	4	1585	7.9E-04	Rupture test	ESA	652, 2314
7/1/68	Cascade	UF_6	18	5	0.9	18	4.4E-05	Purge cascade calculations	ESA	3189
7/13/68	K-1131	UF_6	153	0.4	0.6	152	8.5E-05	Leak through purge valve	EIVA	1441, 2314
8/1/68	Cascade	UF_6	11	5	0.5	10	2.6E-05	Purge cascade calculations	ESA	3189
9/1/68	Cascade	UF_6	11	5	0.5	10	2.5E-05	Purge cascade calculations	ESA	3189
10/1/68	Cascade	UF_6	8	5	0.4	8	2.0E-05	Purge cascade calculations	ESA	3189
11/1/68	Cascade	UF_6	8	5	0.4	8	2.0E-05	Purge cascade calculations	ESA	3189
12/1/68	Cascade	UF_6	8	5	0.4	8	1.9E-05	Purge cascade calculations	ESA	3189
1/1/69	Cascade	UF_6	9	5	0.4	8	2.1E-05	Purge cascade calculations	ESA	3189
2/1/69	Cascade	UF_6	10	5	0.5	9	2.3E-05	Purge cascade calculations	ESA	3189

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
3/1/69	Cascade	UF_6	9	5	0.5	9	2.2E-05	Purge cascade calculations	ESA	3189
4/1/69	Cascade	UF_6	11	5	0.5	10	2.6E-05	Purge cascade calculations	ESA	3189
5/1/69	Cascade	UF_6	10	5	0.5	9	2.3E-05	Purge cascade calculations	ESA	3189
5/5/69	K-1423	UF_6	6746	0.71	48	6698	4.5E-03	Valve seat on cylinder leaked	CIVA	952, 1441 2314
6/1/69	Cascade	UF_6	11	5	0.6	11	2.7E-05	Purge cascade calculations	ESA	3189
7/1/69	K-1131	UF_6	153	0.2	0.0	153	7.3E-05	leak in air system vented to atmosphere	EIVA	2885
8/1/69	K-1423	UF_6	920	0.711	7	913	6.2E-04	During feed cylinder operation, difficulty was encountered in obtaining a sample; several successive cold trap evacuations resulted in the UF6 discharge	ESA	2885
8/13/69	K-1423	UF_6	920	0.8	7	913	6.4E-04	Difficulty in obtaining sample in a routine sampling of feed cylinder.	CIVA	1441, 2314
9/1/69	K-1423	UF_6	613	1.5	9	604	5.9E-04	During cylinder sampling operation the evacuation valve remained open thus resulting in a UF6 release	CIVA	2885
9/8/69	K-1423	UF_6	613	1.5	9	604	5.9E-04	Valve not closed while sampling cylinder	CIVA	1441, 2314
5/24/70	K-33	UF_6	4600	1.5	69	4531	4.5E-03	Control valve bellows in feed header cracked	EIVA	652, 1441
9/26/70	K-413	UF_6	1379	3.0	42	1337	2.2E-03	Drain line leakage - outdoors	EIVA	652, 1441, 2314
1/16/71	K-1131	UF_6	50	0.4	0.2	50	2.8E-05	Disconnected pigtail from cylinder	CIVA	1441
2/1/71	K-602	UF_6	0.1	1	0.001	0.1	7.1E-08	Release Point # G-20 (Pump Seals)	ESA	761
2/1/71	K-413	UF_6	0.4	5	0.02	0.4	9.5E-07	Release Point # G-14 (Pump Seals)	ESA	761
2/1/71	K-633	UF_6	0.4	0.4	0.002	0.4	2.2E-07	Release Point # G-17 (Pump Seals)	ESA	761
2/1/71	K-902	UF_6	1	0.711	0.005	0.7	5.0E-07	Release Point # G-23 (Pump Seals)	ESA	761
2/1/71	K-633	UF_6	20	0.4	0.1	20	1.1E-05	Release Point # G-18 (Test Loop Equipment)	ESA	761

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
2/1/71	K-1131	UF_6	34	0.711	0.2	34	2.3E-05	Cut evacuation line in autoclave -atmosphere	ESA	2314
2/1/71	K-502	UF_6	60	5	3	57	1.4E-04	Release Point # G-15 (Cascade Equipment)	ESA	761
2/1/71	K-502	UF_6	71	5	4	68	1.7E-04	Release Point # G-16 (Pump Seals)	ESA	761
2/1/71	K-310-3	UF_6	143	5	7	136	3.4E-04	Release Point # G-10 (Pump Seals)	ESA	761
2/1/71	K-311-1	UF_6	143	5	7	136	3.4E-04	Release Point # G-11 (Pump Seals)	ESA	761
2/1/71	K-602	UF_6	185	1	2	183	1.4E-04	Release Point # G-21 (Cascade Equipment)	ESA	761
2/1/71	K-902	UF_6	211	0.711	2	210	1.4E-04	Release Point # G-22 (Cascade Equipment)	ESA	761
2/1/71	K-311-1	UF_6	24500	5	1225	23275	5.8E-02	Release Point # G-13 (Cascade Purge)	ESA	761
3/1/71	K-413	UF_6	1	5	0.03	0.5	1.2E-06	Release Point # G-14 (Pump Seals)	ESA	761
3/1/71	K-633	UF_6	1	0.4	0.002	0.5	2.8E-07	Release Point # G-17 (Pump Seals)	ESA	761
3/1/71	K-602	UF_6	5	1	0.05	4	3.5E-06	Release Point # G-20 (Pump Seals)	ESA	761
3/1/71	K-633	UF_6	14	0.4	0.1	13	7.5E-06	Release Point # G-19 (Test Loop Equipment)	ESA	761
3/1/71	K-633	UF_6	20	0.4	0.1	20	1.1E-05	Release Point # G-18 (Test Loop Equipment)	ESA	761
3/1/71	K-502	UF_6	60	5	3	57	1.4E-04	Release Point # G-15 (Cascade Equipment)	ESA	761
3/1/71	K-902	UF_6	71	0.711	0.5	70	4.8E-05	Release Point # G-23 (Pump Seals)	ESA	761
3/1/71	K-502	UF_6	96	5	5	91	2.3E-04	Release Point # G-16 (Pump Seals)	ESA	761
3/1/71	K-602	UF_6	132	1	1	131	1.0E-04	Release Point # G-21 (Cascade Equipment)	ESA	761
3/1/71	K-310-3	UF_6	143	5	7	136	3.4E-04	Release Point # G-10 (Pump Seals)	ESA	761
3/1/71	K-311-1	UF_6	143	5	7	136	3.4E-04	Release Point # G-11 (Pump Seals)	ESA	761
3/1/71	K-902	UF_6	159	0.711	1	157	1.1E-04	Release Point # G-22 (Cascade Equipment)	ESA	761

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
3/1/71	K-311-1	UF_6	3633	5	182	3451	8.7E-03	Release Point # G-13 (Cascade Purge)	ESA	761
4/1/71	K-1131	UF_6	1	0.711	0.01	1	6.7E-07	Sample line leaked - atmosphere	EIVA	2314
4/26/71	K-1401	UF_6	11040	0.71	78	10962	7.4E-03	Copper pigtail ruptured	CIVA	652, 1441
8/1/71	K-311-1	UF_6	613	3.1	19	594	9.9E-04	Rupture cylinder pigtail	EIVA	2314
8/1/71	K-1131	UF_6	920	0.7	6	914	6.0E-04	Sample tube rupture - atmosphere	EIVA	2314
8/24/71	K-311-1	UF_6	7663	3.4	263	7400	1.3E-02	Casing of Cell 5--1B pump ruptured	EIVA	652, 1441, 2314
10/1/71	K-1131	UF_6	920	0.4	4	916	5.1E-04	Sample tube ruptured	EIVA	1441
2/1/72		UF_6	7473	0.711	53	7420	5.0E-03	UF6 used in cell out-leakage testing	EIVA	2885
3/1/72	N/A	UF_6	7473	0.7	53	7420	5.0E-03	Cell outleakage test - atmosphere	ESA	2314
7/1/72	K-311-1	UF_6	1480	3.3	49	1431	2.5E-03	Purge vent stack	ESA	2314
8/1/72	K-311-1	UF_6	800	3.5	28	772	1.4E-03	Purge vent stack	ESA	2314
9/1/72	K-311-1	UF_6	1210	3.6	44	1166	2.2E-03	Purge vent stack	ESA	2314
11/25/72	K-633	UF_6	3067	0.4	12	3055	1.7E-03	Failed heating element caused cold spot in a charge line; material subsequently vaporized	EIVA	1441
12/1/72	K-311-1	UF_6	3720	3.8	140	3580	7.0E-03	Purge vent stack	ESA	2314
2/1/73	K-311-1	UF_6	5100	3.6	184	4916	9.3E-03	Purge vent stack	ESA	2314
3/1/73	K-311-1	UF_6	11100	3.6	401	10699	2.0E-02	Purge vent stack	ESA	2314
4/1/73	K-311-1	UF_6	3300	3.8	125	3175	6.2E-03	Purge vent stack	ESA	2314
5/1/73	K-311-1	UF_6	1300	3.5	45	1255	2.3E-03	Purge vent stack	ESA	2314
6/1/73	K-311-1	UF_6	870	3.4	30	840	1.5E-03	Purge vent stack	ESA	2314
7/1/73	K-311-1	UF_6	610	3.4	21	589	1.1E-03	Purge vent stack	ESA	2314
7/16/73	K-1004-A	UF_6	3600	0.71	26	3574	2.4E-03	Ruptured valve on sample cylinder	CIVA	652, 2314
8/1/73	K-311-1	UF_6	410	3.4	14	396	7.1E-04	Purge vent stack	ESA	2314
8/1/73	K-311-1	UF_6	520	3.3	17	503	8.7E-04	Purge vent stack	ESA	2314
8/27/73	K-1423	UF_6	1533	3	46	1487	2.4E-03	defective valve	CIVA	2884
9/1/73	K-311-1	UF_6	400	3.25	13	387	6.7E-04	Purge vent stack	ESA	2314
10/1/73	K-311-1	UF_6	930	3.3	31	899	1.6E-03	Purge vent stack	ESA	2314

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
11/1/73	K-311-1	UF_6	310	3.2	10	300	5.1E-04	Purge vent stack	ESA	2314
11/25/73	K-633	UF_6	3066	0.33	10	3056	1.6E-03	Block valve leak to air ejector	EIVA	952
8/23/74	K-413	UF_6	307	5	15	292	7.3E-04	Corrosion on an instrument line caused release	EIVA	491
11/1/74	K-1131	UF_6	68	0.711	0.5	67	4.5E-05	pigtail not purged	CIVA	2884
12/19/74	K-1131	UF_6	68	0.7115	0.5	67	4.5E-05	Instrument line ruptured due to plug	EIVA	2313
5/9/75	K-902-5	UF_6	7	0.711	0.05	7	4.6E-06	Maintenance on poorly evacuated main	EIVA	2313
7/1/75	Cascade	UF_6	10	5	0.5	9	2.3E-05	Purge cascade calculations	ESA	3189
8/1/75	Cascade	UF_6	11	5	0.5	10	2.6E-05	Purge cascade calculations	ESA	3189
9/1/75	Cascade	UF_6	8	5	0.4	8	2.0E-05	Purge cascade calculations	ESA	3189
9/17/75	K-1423	UF_6	5519	3.3	179	5340	9.2E-03	Cracked valve and cylinder wall	CIVA	652
10/1/75	Cascade	UF_6	9	5	0.5	9	2.2E-05	Purge cascade calculations	ESA	3189
11/1/75	K-311-1	UF_6	2210	3.5	77	2133	3.9E-03	Purge	ESA	631
11/1/75	K-311-1	UF_6	2820	3.5	100	2720	5.0E-03	Purge	ESA	631
11/1/75	Cascade	UF_6	10	5	0.5	10	2.4E-05	Purge cascade calculations	ESA	3189
12/1/75	Cascade	UF_6	11	5	0.6	11	2.7E-05	Purge cascade calculations	ESA	3189
1/1/76	K-311-1	UF_6	1730	5	87	1644	4.1E-03	Vented to atmosphere.	ESA	631
1/1/76	Cascade	UF_6	13	5	0.6	12	3.0E-05	Purge cascade calculations	ESA	3189
2/1/76	Cascade	UF_6	12	5	0.6	11	2.8E-05	Purge cascade calculations	ESA	3189
3/1/76	K-311-1	UF_6	40	3.3	1	39	6.8E-05	Purge	ESA	631
3/1/76	K-311-1	UF_6	2420	3.7	89	2331	4.4E-03	Purge	ESA	631
3/1/76	K-311-1	UF_6	2820	3.3	93	2727	4.8E-03	Purge	ESA	631
3/1/76	K-311-1	UF_6	400	3.3	13	387	6.8E-04	Purge	ESA	631
3/1/76	Cascade	UF_6	12	5	0.6	12	2.9E-05	Purge cascade calculations	ESA	3189
3/1/76	K-33	UF_6	1189	1	12	1177	9.3E-04	series of UF6 test releases in K-33 building to test ventilation	EIVA	2824
3/11/76	K-402-9	UF_6	225	3.6	8	217	4.1E-04	Accidental release from the purge stack - HP found 150 g U on the K-402-9 roof	ESA	631, 2313

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
4/1/76	Cascade	UF_6	19	5	0.9	18	4.5E-05	Purge cascade calculations	ESA	3189
5/1/76	K-311-1	UF_6	1840	3	55	1785	2.9E-03	Purge	ESA	631
5/1/76	K-311-1	UF_6	1970	3	59	1911	3.1E-03	Purge	ESA	631
5/1/76	Cascade	UF_6	14	5	0.7	13	3.3E-05	Purge cascade calculations	ESA	3189
6/1/76	K-311-1	UF_6	1660	3.5	58	1602	2.9E-03	Purge	ESA	631
6/1/76	Cascade	UF_6	13	5	0.7	13	3.2E-05	Purge cascade calculations	ESA	3189
6/5/76	K-413	UF_6	135	5	7	128	3.2E-04	failed seal	EIVA	2884
6/9/76	K-1420	UF_6	338	0.7	2	336	2.2E-04	Material released when valve was opened for repair	EIVA	2313
7/1/76	K-413	UF_6	200	3.0	6	194	3.1E-04	Failed seal.	EIVA	631
7/1/76	K-311-1	UF_6	2370	3.5	83	2287	4.2E-03	Purge	ESA	631
9/1/76	K-902-5	UF_6	50	0.711	0.4	50	3.4E-05	Cracked valve.	EIVA	631
9/1/76	K-311-1	UF_6	10010	5	501	9510	2.4E-02	Emission	ESA	631
9/1/76	K-311-1	UF_6	11770	5	589	11182	2.8E-02	Emission	ESA	631
9/17/76	K-33	UF_6	34	1	0.3	33	2.6E-05	Valve opened to relieve pressure releasing material	EIVA	2313
10/18/76	K-602-3	UF_6	7	1.2	0.1	7	5.8E-06	Datum failure caused downsurge and release thru seal	EIVA	631, 2313
11/1/76	K-311-1	UF_6	3790	3.1	117	3673	6.1E-03	Purge	ESA	631
12/1/76	K-602-5	UF_6	3	1.2	0.04	3	2.9E-06	Puff of smoke emanated from between the seats of valve.	EIVA	631, 2313
12/1/76	Cascade	UF_6	1300	3.5	46	1254	2.3E-03	Purge	ESA	631
2/1/77	Cascade	UF_6	1150	5	58	1093	2.7E-03	Purge emissions.	ESA	631
3/1/77	Cascade	UF_6	2390	5	120	2271	5.7E-03	Purge emissions.	ESA	631
3/1/77	K-413	UF_6	3070	2.9	89	2981	4.7E-03	Accidental release, pigtail pinch-off incomplete	CIVA	652, 631
3/1/77	Cascade	UF_6	4250	5	213	4038	1.0E-02	Purge emissions.	ESA	631
4/1/77	Cascade	UF_6	1340	5	67	1273	3.2E-03	Purge emissions.	ESA	631
5/1/77	N/A	UF_6	1000	5	50	950	2.4E-03	Chemical trap gasket.	EIVA	631

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
5/18/77	K-33	UF_6	1533	0.8	12	1521	1.1E-03	Accidental release, leak around pump exhaust gasket	EIVA	652, 2313
6/1/77	Cascade	UF_6	1270	5	64	1207	3.0E-03	Purge emissions.	ESA	631
7/1/77	Cascade	UF_6	2	5	0.1	2	4.8E-06	Purge emission.	ESA	631
8/1/77	Cascade	UF_6	40	5	2	38	9.5E-05	Purge emission.	ESA	631
8/1/77	Cascade	UF_6	50	5	3	48	1.2E-04	Purge emission	ESA	631
11/1/77	Cascade	UF_6	1240	5	62	1178	3.0E-03	Purge emissions.	ESA	631
12/1/77	Cascade	UF_6	334	5	17	317	8.0E-04	Purged to atmosphere	ESA	631
1/1/78	Cascade	UF_6	484	5	24	460	1.2E-03	Cascade emission	ESA	631
1/1/78	Cascade	UF_6	630	5	32	599	1.5E-03	Cascade emission	ESA	631
2/1/78	Cascade	UF_6	25	5	1	24	6.0E-05	Cascade emission	ESA	631
3/1/78	Cascade	UF_6	380	5	19	361	9.1E-04	Cascade emission.	ESA	631
3/19/78	K-1210	UF_6	4302	0.711	31	4271	2.9E-03	Gasket failure from over heating	EIVA	652
4/1/78	Cascade	UF_6	554	5	28	526	1.3E-03	Cascade emission	ESA	652
5/1/78	Cascade	UF_6	551	5	28	523	1.3E-03	Cascade emission.	ESA	631
6/1/78	Cascade	UF_6	121	5	6	115	2.9E-04	Cascade emission	ESA	631
7/1/78	Cascade	UF_6	274	5	14	260	6.5E-04	Cascade emission.	ESA	631
8/1/78	Cascade	UF_6	127	5	6	121	3.0E-04	Cascade emission	ESA	631
10/1/78	Cascade	UF_6	87	5	4	83	2.1E-04	Cascade emission	ESA	631
12/1/78	Cascade	UF_6	1763	5	88	1675	4.2E-03	Purge to atmosphere	ESA	631
2/1/80	Cascade	UF_6	840	5	42	798	2.0E-03	Enriched	ESA	631
3/30/80	K-31	UF_6	50	2	1	49	5.9E-05	Valve had ruptured bellows	EIVA	1405
4/29/80	K-402-9	UF_6	1	5	0.1	1	2.4E-06	Faulty thermocouple connection	EIVA	1405
6/17/80	K-1131	UF_6	1	0.711	0.01	1	6.7E-07	Feed system	EIVA	1405
7/28/80	K-1413	UF_6	5827	0.71	41	5786	3.9E-03	Valving error involving an MD cylinder	CIVA	652, 1405
9/20/80	K-402-9	UF_6	1	5	0.1	1	2.4E-06	Maintenance activity	EIVA	1405
10/24/80	K-413	UF_6	1	5	0.1	1	2.4E-06	Release at sample manifold	EIVA	1405
11/26/80	K-413	UF_6	1	5	0.1	1	2.4E-06	Release due to bad bellows	EIVA	1405

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
12/1/80	K-1302	UF_6	1533	3.2	49	1484	2.5E-03	Stack release caused by valving error	ESA	652, 1405
12/2/80	K-29	UF_6	1	3	0.03	1	1.6E-06	Loose seal feed line	EIVA	1405
1/13/81	K-1423	UF_6	5	5	0.3	5	1.2E-05	Pigtail leaking	CIVA	1405
5/27/81	K-29	UF_6	2000	3.2	64	1936	3.3E-03	Release from cell following high temperature reaction	EIVA	652
5/27/81	K-29	UF_6	2000	3.2	64	1936	3.3E-03	Ruptured breached converter	EIVA	652, 1405
8/19/82	K-1131	UF_6	1	0.4	0.004	1	5.5E-07	Bearing failure on tails pump	EIVA	1405
10/1/82	K-402-9	UO_3	41	3.2	1	39	6.7E-05		ESA	2959
10/11/82	K-413	UF_6	1	5	0.1	1	2.4E-06	Withdrawal equipment smoked	EIVA	1405
11/1/82	K-402-9	UO_3	42	3.2	1	40	6.9E-05		ESA	2959
12/1/82	K-402-9	UO_3	176	3.2	6	171	2.9E-04		ESA	2959
1/1/83	K-402-9	UO_3	109	3.2	3	106	1.8E-04		ESA	2959
2/1/83	K-402-9	UO_3	40	3.2	1	39	6.6E-05		ESA	2959
3/1/83	K-402-9	UO_3	62	3.2	2	60	1.0E-04		ESA	2959
4/1/83	K-402-9	UO_3	66	3.2	2	64	1.1E-04		ESA	2959
5/1/83	K-402-9	UO_3	37	3.2	1	35	6.0E-05		ESA	2959
6/1/83	K-402-9	UO_3	42	3.2	1	41	7.0E-05		ESA	2959
7/1/83	K-402-9	UO_3	35	3.2	1	34	5.8E-05		ESA	2959
8/1/83	K-402-9	UO_3	113	3.2	4	110	1.9E-04		ESA	2959
9/1/83	K-402-9	UO_3	44	3.2	1	43	7.3E-05		ESA	2959
10/1/83	K-402-9	UO_3	39	3.5	1	38	6.9E-05	purge vent and scrubber, monthly	ESA	2959
11/1/83	K-402-9	UO_3	37	3.5	1	35	6.5E-05	purge vent and scrubber, monthly	ESA	2959
12/1/83	K-402-9	UO_3	41	3.5	1	39	7.2E-05	purge vent and scrubber, monthly	ESA	2959
1/1/84	K-402-9	UO_3	31	3.5	1	30	5.5E-05	purge vent and scrubber, monthly	ESA	2959
1/1/84	K-402-9	UO_3	40	3.5	1	39	7.1E-05	purge vent and scrubber, monthly	ESA	2959
2/1/84	K-402-9	UO_3	27	3.5	1	26	4.9E-05	purge vent and scrubber, monthly	ESA	2959
2/9/84	K-402-9	UF_6	1	5	0.1	1	2.4E-06	Valve leak	EIVA	1405, 2313
2/24/84	K-413	UF_6	1	5	0.1	1	2.4E-06	Peanut valve	EIVA	1405, 2313
3/1/84	K-402-9	UO_3	19	3.5	0.7	18	3.4E-05	purge vent and scrubber, monthly	ESA	2959
3/15/84	K-631	UF_6	1	0.4	0.004	1	5.5E-07	Valve change	EIVA	1405, 2313

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
4/1/84	K-402-9	UO_3	10	3.5	0.3	10	1.8E-05	purge vent and scrubber, monthly	ESA	2959
4/1/84	K-633	UF_6	1	0.4	0.004	1	5.5E-07	Motor shaft	EIVA	1405, 2313
5/1/84	K-402-9	UO_3	41	3.5	1	39	7.2E-05	purge vent and scrubber, monthly	ESA	2959
5/3/84	K-402-9	UF_6	1	5	0.1	1	2.4E-06	Changing seal	EIVA	1405, 2313
5/22/84	K-402-9	UF_6	1	5	0.1	1	2.4E-06	Changing seal	EIVA	1405, 2313
6/1/84	K-402-9	UO_3	13	3.5	0.5	13	2.4E-05	purge vent and scrubber, monthly	ESA	2959
6/5/84	K-413	UF_6	1	5	0.1	1	2.4E-06	Sample tube developed crack	EIVA	1405, 2313
7/1/84	K-402-9	UO_3	11	3.5	0.4	10	1.9E-05	purge vent and scrubber, monthly	ESA	2959
8/1/84	K-402-9	UO_3	11	3.5	0.4	10	1.9E-05	purge vent and scrubber, monthly	ESA	2959
8/1/84	K-33	UF_6	1	1	0.01	1	7.8E-07	Valve removal	EIVA	1405, 2313
9/1/84	K-402-9	UO_3	22	3.5	0.8	21	3.8E-05	purge vent and scrubber, monthly	ESA	2959
9/21/84	K-413	UF_6	1	5	0.1	1	2.4E-06	Cutting vent line	EIVA	1405, 2313
9/27/84	K-1413	UF	5	0.711	0.03	5	3.1E-06	pigtail leaked when disconnected	EIVA	2959
9/28/84	K-29	UF_6	1	3	0.03	1	1.6E-06	Outgas from 2A seal	EIVA	1405, 2313
10/1/84	K-402-9	UO_3	92	3.5	3	88	1.6E-04	purge vent and scrubber, monthly	ESA	2959
11/1/84	K-402-9	UO_3	16	3.5	0.6	15	2.8E-05	purge vent and scrubber, monthly	ESA	2959
11/15/84	K-29	UF_6	1	3	0.03	1	1.6E-06	Seal failure	EIVA	1405, 2313
11/30/84	K-33	UF_6	1	1	0.01	1	7.8E-07	Cut into line	EIVA	1405, 2313
12/1/84	K-402-9	UO_3	11	3.5	0.4	10	1.9E-05	purge vent and scrubber, monthly	ESA	2959
1/10/85	K-402-9	UF_6	1	5	0.1	1	2.4E-06	Release from seal cavity	EIVA	1405, 2313
1/17/85	K-31	UF_6	1	2	0.02	1	1.2E-06	Changing compressor	EIVA	1405, 2313
1/18/85	K-413	UF_6	135	n/a				small pinhole in process piping over three week period	EIVA	2959
2/1/85	K-402-9	UO_3	17	3.5	0.6	16	2.9E-05	purge vent and scrubber, monthly	ESA	2959
2/4/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Leaking valve	EIVA	1405, 2313
3/1/85	K-402-9	UO_3	4	3.5	0.1	4	7.1E-06	purge vent and scrubber, monthly	ESA	2959
4/1/85	K-402-9	UO_3	15	3.6	0.5	14	2.7E-05	purge vent and scrubber, monthly	ESA	2959
4/1/85	K-29	UF_6	1	3	0.03	1	1.6E-06	Smoking valve	EIVA	1405, 2313
4/15/85	Railyard	UF_6	20	0.6	0.1	20	1.3E-05	Leaking valve	EIVA	1405, 2313

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
4/16/85	K-1423	UF_6	70	5	4	67	1.7E-04	Drain line blew out when changing cylinders	CIVA	1405, 2313
4/25/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Cut in south drain manifold	EIVA	1405, 2313
4/26/85	K-413	UF_6	5	5	0.3	5	1.2E-05	Valve leaking	EIVA	1405, 2313
4/29/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Cutting into valve buffer line	EIVA	1405, 2313
5/1/85	K-402-9	UO_3	57	3.6	2	55	1.0E-04	purge vent and scrubber, monthly	ESA	2959
5/8/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Outgassing of residual deposit in drain line	ESA	2313
5/9/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Outgassing of residual deposits in drain line	ESA	2313
5/13/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Outgassing of residual deposits in drain line	ESA	2313
5/13/85	K-413	UF_6	1	n/a				outgassing from small residual deposit in instrument line	EIVA	2959
5/15/85	K-413	UF_6	1	n/a				residual deposit in drain line	EIVA	2959
5/16/85	K-413	UF_6	1	5	0.1	1	2.4E-06	Outgassing from deposit in south sample box tubing	ESA	2313
5/19/85	K-502-3	UF_6	1	5	0.1	1	2.4E-06	K-502-3.1.8 was shut down for 8A seal change, cell was slightly above atmospheric pressure	EIVA	2313
5/23/85	K-27-9	UF_6	1	n/a				small deposit escaped from seal cavity	EIVA	2959
6/1/85	K-402-9	UO3	24	3.6	0.9	23	4.4E-05	purge vent and scrubber, monthly	ESA	2959
7/15/85	K-1423	UF_6	17	3	0.5	16	2.7E-05	ruptured cylinder drain line	CIVA	2959
7/30/85	K-31	UF_6	676	n/a				residual in line blown out stack	ESA	2978
9/11/85	K-1004-A	UF_6	7	0.711	0.05	7	4.5E-06	cylinder connector leaked	CIVA	2959
9/21/88	ORGDP	UF_6	459864	0.711	3270	456565	3.1E-01	large drum fell off pallet and broke; spill was contained and cleaned up		2978
9/25/88	ORGDP	UF_6	3066	0.711	22	3044	2.1E-03	liquid spill from a mixing truck, material was picked up and put back into the mixer; area was cleaned		2978

Table E-1
K-25 Accountability Records: Atmospheric Release

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	ChemRisk Repository Number
1/1/93	K-1004-L	n/a	87	0.69	0.6	86	5.9E-05	releases from lab hoods	ESA	3412
1/1/93	TSCA	n/a	11984	0.66	79	11905	8.0E-03	releases from TSCA	ESA	3412
1/1/93	K-1008-C	n/a	2	0.67	0.01	2	1.2E-06	releases from respirator hoods	ESA	3412
1/1/93	K-1435	n/a	186	0.67	1	185	1.2E-04	(atmospheric) releases from waste feed tanks	ESA	3412
1/1/94	K-1004	n/a	154	0.71	1	153	1.0E-04	releases from lab hoods	ESA	3417
1/1/94	K-1006	n/a	14	0.71	0.1	14	9.6E-06	releases from lab hoods	ESA	3417
1/1/94	K-1004-L	n/a	138	0.71	1	137	9.3E-05	releases from lab hoods	ESA	3417
1/1/94	TSCA	n/a	5966	0.71	43	5923	4.0E-03	releases from TSCA	ESA	3417
1/1/94	K-1435	n/a	179	0.71	1	178	1.2E-04	(atmospheric) releases from waste feed tanks	ESA	3417
1/1/94	K-1430-A	n/a	1211	0.71	9	1202	4.4E-04	releases from lab hoods	ESA	3417
1/1/94	K-31	n/a	1000	3	30	970	1.6E-03	removal of cascade equipment	EIVA	3417

Table E-2: K-25 Accountability Records: New Data 10-31-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference
2/25/58	K-1401	UF6	30.7	0.711	0.2	30.5	2.062E-05		ESA	4
3/5/58	K-1401	UF6	15.3	0.711	0.1	15.2	1.031E-05		ESA	4
3/13/58	K-1401	UF6	30.7	0.711	0.2	30.5	2.062E-05		ESA	4
3/21/58	K-1401	UF6	6.2	0.711	0.0	6.1	4.133E-06		ESA	4
5/8/58	K-1401	UF6	61.3	0.711	0.4	60.9	4.120E-05		ESA	4
10/15/58	K-1401	UF6	306.6	0.711	2.2	304.4	2.060E-04		ESA	4
1/19/59	K-1413	UF6	459.9	0.711	3.3	456.6	3.090E-04		ESA	3
3/8/59	K-1413	UF6	306.6	0.711	2.2	304.4	2.060E-04		ESA	3
10/18/59	K-1401	UF6	30.7	0.711	0.2	30.5	2.062E-05		ESA	3
10/26/59	K-1413	UF6	306.6	0.711	2.2	304.4	2.060E-04		ESA	3
11/11/59	K-1413	UF6	70.5	0.711	0.5	70.0	4.737E-05		ESA	3
10/1/82	K-402-9	UO3	40.8	3.2	1.30	39.46	6.730E-05		ESA	2
11/1/82	K-402-9	UO3	41.6	3.2	1.33	40.27	6.867E-05		ESA	2
12/1/82	K-402-9	UO3	176.4	3.2	5.64	170.74	2.912E-04		ESA	2
1/1/83	K-402-9	UO3	109.0	3.2	3.49	105.50	1.799E-04		ESA	2
2/1/83	K-402-9	UO3	39.9	3.2	1.28	38.66	6.593E-05		ESA	2
3/1/83	K-402-9	UO3	61.6	3.2	1.97	59.60	1.016E-04		ESA	2
4/1/83	K-402-9	UO3	65.7	3.2	2.10	63.62	1.085E-04		ESA	2
5/1/83	K-402-9	UO3	36.6	3.2	1.17	35.44	6.043E-05		ESA	2
6/1/83	K-402-9	UO3	42.4	3.2	1.36	41.07	7.005E-05		ESA	2
7/1/83	K-402-9	UO3	34.9	3.2	1.12	33.83	5.769E-05		ESA	2
8/1/83	K-402-9	UO3	113.2	3.2	3.62	109.53	1.868E-04		ESA	2
9/1/83	K-402-9	UO3	44.1	3.2	1.41	42.68	7.279E-05		ESA	2
10/1/83	K-402-9	UO3	39.1	3.5	1.37	37.74	6.928E-05	purge vent and scrubber, monthly	ESA	2
11/1/83	K-402-9	UO3	36.6	3.5	1.28	35.33	6.486E-05	purge vent and scrubber, monthly	ESA	2
12/1/83	K-402-9	UO3	40.8	3.5	1.43	39.34	7.223E-05	purge vent and scrubber, monthly	ESA	2
1/1/84	K-402-9	UO3	30.8	3.5	1.08	29.71	5.454E-05	purge vent and scrubber, monthly	ESA	2
1/1/84	K-402-9	UO3	39.9	3.5	1.40	38.54	7.075E-05	purge vent and scrubber, monthly	ESA	2
2/1/84	K-402-9	UO3	27.5	3.5	0.96	26.50	4.864E-05	purge vent and scrubber, monthly	ESA	2
3/1/84	K-402-9	UO3	19.1	3.5	0.67	18.47	3.390E-05	purge vent and scrubber, monthly	ESA	2
4/1/84	K-402-9	UO3	10.0	3.5	0.35	9.63	1.769E-05	purge vent and scrubber, monthly	ESA	2
5/1/84	K-402-9	UO3	40.8	3.5	1.43	39.34	7.223E-05	purge vent and scrubber, monthly	ESA	2
6/1/84	K-402-9	UO3	13.3	3.5	0.47	12.85	2.358E-05	purge vent and scrubber, monthly	ESA	2
7/1/84	K-402-9	UO3	10.8	3.5	0.38	10.44	1.916E-05	purge vent and scrubber, monthly	ESA	2
8/1/84	K-402-9	UO3	10.8	3.5	0.38	10.44	1.916E-05	purge vent and scrubber, monthly	ESA	2
9/1/84	K-402-9	UO3	21.6	3.5	0.76	20.87	3.832E-05	purge vent and scrubber, monthly	ESA	2
9/27/84	K-1413	UF	4.6	0.711	0.03	4.60	3.111E-06	pigtail leaked when disconnected	EIVA	2
10/1/84	K-402-9	UO3	91.5	3.5	3.20	88.32	1.621E-04	purge vent and scrubber, monthly	ESA	2
11/1/84	K-402-9	UO3	15.8	3.5	0.55	15.25	2.801E-05	purge vent and scrubber, monthly	ESA	2
11/15/84	K-29	UF6	67.6	n/a				seal failure	EIVA	2
12/1/84	K-402-9	UO3	10.8	3.5	0.38	10.44	1.916E-05	purge vent and scrubber, monthly	ESA	2
1/18/85	K-413	UF6	135.2	n/a				small pinhole in process piping over three week period	EIVA	2
2/1/85	K-402-9	UO3	16.6	3.5	0.58	16.06	2.948E-05	purge vent and scrubber, monthly	ESA	2
3/1/85	K-402-9	UO3	4.0	3.5	0.14	3.85	7.075E-06	purge vent and scrubber, monthly	ESA	2

Table E-2: K-25 Accountability Records: New Data 10-31-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference
4/1/85	K-402-9	UO3	15.0	3.6	0.54	14.44	2.714E-05	purge vent and scrubber, monthly	ESA	2
4/16/85	K-1423	UF6	47.3	3.5	1.66	45.66	8.383E-05	plug blew out of drain line causing release	EIVA	2
4/25/85	K-413	UF6	0.7	n/a				cut into piping and small deposit gassed off	EIVA	2
4/26/85	K-413	UF6	3.4	n/a				small leak on newly installed drain manifold block valve	EIVA	2
5/1/85	K-402-9	UO3	57.4	3.6	2.07	55.34	1.040E-04	purge vent and scrubber, monthly	ESA	2
5/8/85	K-413	UF6	0.7	n/a				outgassing from residual deposit in drain line	EIVA	2
5/9/85	K-413	UF6	0.7	n/a				outgassing from residual deposit in drain line	EIVA	2
5/13/85	K-413	UF6	0.7	n/a				outgassing from small residual deposit in instrument line	EIVA	2
5/15/85	K-413	UF6	0.7	n/a				residual deposit in drain line	EIVA	2
5/16/85	K-413	UF6	0.7	n/a				outgassing from deposit in tubing	EIVA	2
5/19/85	K-502-2	UF6	0.7	n/a				cell stage outgassed	EIVA	2
5/23/85	K-27-9	UF6	0.7	n/a				small deposit escaped from seal cavity	EIVA	2
6/1/85	K-402-9	UO3	24.1	3.6	0.87	23.26	4.372E-05	purge vent and scrubber, monthly	ESA	2
7/15/85	K-1423	UF6	16.9	3	0.51	16.39	2.654E-05	ruptured cylinder drain line	CIVA	2
7/30/85	K-31	UF6	676.0	n/a				residual in line blown out stack	ESA	1
9/11/85	K-1004-A	UF6	6.8	0.711	0.0	6.7	4.542E-06	cylinder connector leaked	CIVA	2
9/21/88	ORGDP	UF6	459863.9	0.711	3269.6	456565.3	3.090E-01	large drum fell off pallet and broke; spill was contained and cleaned up		1
9/25/88	ORGDP	UF6	3065.7	0.711	21.8	3043.7	2.060E-03	liquid spill from a mixing truck, material was returned to the mixer; area was cleaned		1

1 Buddenbaum J.E., 1995. Interview Notes: William Tucker, Y-12 Analytical Laboratory. ChemRisk Repository No. 2978

2 Estes K.D., Tomlinson B.W., Whited R.W. Unknown Document Number. ChemRisk Repository No. 2958

3 Lang D.M. 1959. Air Pollution 1959. Unknown Document Number. ChemRisk Repository No. 2960

4 Stoddard, D. Lang, D.M. 1958. Uranium in Air. Unknown Document Number. ChemRisk Repository No. 2961

Table E-3: K-25 Accountability Records: New Data 8-29-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference	Reference
1/16/50	402-5	UF6	n/a	n/a	n/a	n/a	n/a	hose leaked	EIVA	1	p. 538
3/2/50	K-1301	UF4	n/a	n/a	n/a	n/a	n/a	gasket blew out	EIVA	1	p. 570
12/10/50	402-1	UF6	n/a	n/a	n/a	n/a	n/a	plugged transmitter	EIVA	1	p. 543
1/13/51	K-1131 & K-1410	UF6	n/a	n/a	n/a	n/a	n/a	cracked cold trap	EIVA	1	p. 533-535
2/5/51	310-3	UF6	n/a	n/a	n/a	n/a	n/a	coupling didn't fit properly	EIVA	1	p. 536
2/20/51	K-413	UF6	n/a	n/a	n/a	n/a	n/a	pump blew up	EIVA	1	p. 525
2/22/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	transfer connection broken	CA	1	p. 524
3/7/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	valve leaked	EIVA	1	p. 523
3/13/51	K-1401	UF6	674.5	0.711	4.8	669.7	4.532E-04	high pressure	EIVA	1	p. 522
4/2/51	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	seal	EIVA	1	p. 518
4/4/51	K-1131	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 519
4/13/51	K-1004-D rm 8	UF6	67.6	0.711	0.5	67.1	4.542E-05	blew open	CIVA	1	p. 517
4/17/51	K-101	UF6	n/a	n/a	n/a	n/a	n/a	high pressure	EIVA	1	p. 516
4/19/51	K-631	UF6	n/a	n/a	n/a	n/a	n/a	valve closure	EIVA	1	p. 515
4/25/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	leak rom ma nifold	EIVA	1	p. 514
4/28/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a	phosgene blowing from stack into building	EVA	1	p. 511
5/4/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	leak	EIVA	1	p. 509
5/5/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	cold trap	EVA	1	p. 508
5/7/51	K-1405	UF4	687.5	0.711	4.9	682.6	4.619E-04	broken bellows	EIVA	1	p. 507
5/13/51	K-312-3	UF6	n/a	n/a	n/a	n/a	n/a	unreadable		1	p. 505
5/16/51	K-131	UF6	n/a	n/a	n/a	n/a	n/a	valve	EIVA	1	p. 504
5/23/51	K-1405	UF6	4598.6	0.711	32.7	4565.9	3.090E-03	leaking from valve	EIVA	1	p. 502, 503
7/2/51	unreadable	UF6	n/a	n/a	n/a	n/a	n/a			1	p. 497
8/6/51	K-1004-A rm 19	UF6	67.6	0.711	0.5	67.1	4.542E-05	replacing stuck valve	CIVA	1	p. 495
8/25/51	402-1	UF6	n/a	n/a	n/a	n/a	n/a	ruptured pig tail	CIVA	1	p. 492
9/5/51	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	plug at cylinder head	CIVA	1	p. 491
9/19/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a	flange	EIVA	1	p. 489
9/21/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 488
9/24/51	K-306-2	UF6	n/a	n/a	n/a	n/a	n/a	flange	EIVA	1	p. 471
9/26/51	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	pump	EIVA	1	p. 482
10/5/51	K-1004-D rm 12	UF6	n/a	n/a	n/a	n/a	n/a	valve seal	EIVA	1	p. 481
10/16/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	loose connection	EIVA	1	p. 478
10/18/51	K-1401 rm 204	UF6	2298.4	0.711	16.3	2282.1	1.544E-03	cylinder leaking	CIVA	1	p. 451
11/2/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	flange	EIVA	1	p. 450
11/17/51	K-27 & K-631	UF6	n/a	n/a	n/a	n/a	n/a	seal falure/ cold trap plugged	EIVA	1	p. 442-445
11/17/51	K-631	UF6	n/a	n/a	n/a	n/a	n/a	7 or 8 release points, no info on amount or why	EIVA		p. C-18
12/7/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	flange at top of tower	EIVA	1	p. 439
12/8/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a	head on tower	EIVA	1	p. 438
12/11/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	leak	EIVA	1	p. 437
3/6/52	K-1004-A	UF6	n/a	n/a	n/a	n/a	n/a	rupture in tubing	EIVA	1	p. 428
3/20/52	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	rupture in pump	EIVA	1	p. 425
8/14/52	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	pump head being lifted by crane	EIVA	1	p. 402
8/15/52	K-1401	UF6	268	1.119	3	265	2.223E-04	quarterly decon in K-1401	EIVA		p. C-12
9/9/52	K-131	UF6	n/a	n/a	n/a	n/a	n/a	clamp not tight	CIVA	1	p. 410-413
9/14/52	K-402-7	UF4	n/a	n/a	n/a	n/a	n/a	gasket failed	EIVA	1	p. 409
12/24/52	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	unreadable		1	p. 380
2/13/53	K-1004-J	UF4	n/a	n/a	n/a	n/a	n/a	leaky system	EIVA	1	p. 357
6/4/53	K-1004-A rm 19	UF6	2.7	0.711	0.0	2.7	1.817E-06	tube	EIVA	1	p. 333
6/16/53	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	line not cleared	EIVA	1	p. 324
6/18/53	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	spill	ESA	1	p. 330
7/14/53	K-633	UF4	n/a	n/a	n/a	n/a	n/a	pluggled line/leaking valve	EIVA	1	p. 328
8/31/53	K-1004-C rm 207	UF6	20.3	0.711	0.1	20.1	1.363E-05	cold trap broke	EIVA	1	p. 323
9/5/53	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	plugged line broke loose	EIVA	1	p. 327
9/12/53	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	area around Welsh pump	EIVA	1	p. 325
11/20/53	K-633 Test Loop	UF6	613.2	0.600	3.7	609.5	3.858E-04	operator error	ESA	1	p. 283
12/11/53	K-633	UF6	n/a	n/a	n/a	n/a	n/a	defective gasket	CIVA	1	p. 322
12/29/53	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	discharge head removed from compressor	EIVA	1	p. 313
2/3/54	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	head removed from compressor	EIVA	1	p. 307, 308
2/5/54	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	instrument line burst	EIVA	1	p. 306
4/6/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a			1	p. 301
5/10/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	cold trap	EIVA	1	p. 304
5/11/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	tower area	EVA	1	p. 305
5/12/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 303
5/18/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 302
6/19/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Valve failure	EIVA	1	p. 297
7/29/54	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	defective valve	EIVA	1	p. 281
8/18/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	cylinder valve	CIVA	1	p. 280

Table E-3: K-25 Accountability Records: New Data 8-29-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference	Reference
9/17/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	valve bonnet backed out	EIVA	1	p. 277
9/27/54	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	seal failure	EIVA	1	p. 275, 276
10/30/54	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	compressor	EIVA	1	p. 272
1/19/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Assembly loosened in shell	EIVA	1	p. 268
2/3/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Attempting to remove rotor	EIVA	1	p. 264
2/10/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	While applying heat to shell, gas was released	EIVA	1	p. 262, 263
3/15/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Stator broke loose	EIVA	1	p. 254-259
6/9/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Disassembling compressor	EIVA	1	p. 241-244
6/10/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Dismantling compressor	EIVA	1	p. 239, 240
8/31/55	K-301-1 Cell 4	UF6	119.0	15.000	17.8	101.1	8.168E-04	valving error	ESA	1	p. 198
12/4/55	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Ruptured bellows on product cylinder valve gave 3 - 4 min. release	CIVA	1	p. 190
12/20/55	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Seal failed on pump; 2 hr. release resulted in high air activity	EIVA	1	p. 187
12/24/55	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Release due to valve failure	EIVA	1	p. 185
4/20/56	K-304	UF6	n/a	n/a	n/a	n/a	n/a	209 grams of "X" material which was alpha radioactive; recovered most of material	spilled on road	1	p. 167
5/7/56	K-1131	UF4	n/a	n/a	n/a	n/a	n/a	Bellows leaked and UF4 powder was blown into the air; 2 min. release but no 'smoking' noticed	ESA	1	p. 161
5/25/56	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	Valve on trap failed to seat; 12 min. release	ESA	1	p. 158
8/2/56	"F" avenue, 14th a	UF6	n/a	n/a	n/a	n/a	n/a	Contaminated oil leaked onto streets during transport of pump		1	p. 144
8/15/56	K-1131	UF6	30672	0.300	92	30580	1.577E-02	normal vent emissions from stack	ESA		p. C-11
2/4/57	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	5 min. release when valve was removed	EIVA	1	p. 111
4/12/57	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	Receiver wall burned through releasing UF6	EIVA	1	p. 104
5/27/57	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	Small release when seal failed	EIVA	1	p. 98
6/1/57	K-303-3	UF6	n/a	n/a	n/a	n/a	n/a	2 min. release when attempting to remove UF6 plug	EIVA	1	p. 97
6/11/57	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Release of short duration occurred when dismantling compressor	EIVA	1	p. 95
8/16/57	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Bellows ruptured when valve was opened, 5 min gas release	EIVA	1	p. 89
8/21/57	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Pump seal failure led to gas release for 10 min.	EIVA	1	p. 88
8/24/57	K-1420	UF6	n/a	n/a	n/a	n/a	n/a	Large release trapped process gas escaped	EIVA	1	p. 85
10/28/57	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	Entrapped UF6 in line between cleanup reactor and cold traps vaporized when opened	EIVA	1	p. 79
1/13/58	K-902.4	UF6	307	1.303	4	303	2.766E-04		EIVA		p. C-19
3/11/58	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Packing gland on Beach-Russ pump failed	EIVA	1	p. 55
4/9/58	K-902-4	UF6	n/a	n/a	n/a	n/a	n/a	Small release during seal removal	EIVA	1	p. 33
5/13/58	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	Seal failed, small release	EIVA	1	p. 46
6/1/58	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Valve bellows on cylinder ruptured	CIVA	1	p. 33
6/25/58	K-402-3.6	UF6	205	10.244	21	184	9.531E-04	Line recorder line opened, due to wear, inside cell	EIVA		p. C-19
9/5/58	K-1131 / K-1410	UF4	n/a	n/a	n/a	n/a	n/a	UF4 spill on road between K-1131 and K-1410		1	p. 23
9/24/58	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	UF6 cloud released directly to atmosphere	CA	1	p. 16
7/1/69	K-1131	UF6	153	0.200	0	153	7.285E-05	leak in air system vented to atmosphere	EIVA	2	
8/1/69	K-1423	UF6	920	0.711	7	913	6.181E-04	During feed cylinder operation, difficulty in obtaining a sample; several cold trap evacuations resulted in UF6 discharge	ESA	2	
9/1/69	K-1423	UF6	613.0	1.457	9	604.0	5.889E-04	During cylinder sampling operation the evacuation valve remained open thus resulting in a UF6 release	CIVA	2	
8/15/70	n/a	n/a	n/a	n/a	n/a	n/a	n/a	just one release noted, no other information	n/a	4	p. E-1
2/1/72		UF6	7473.0	0.711	53	7420.0	5.021E-03	UF6 used in cell out-leakage testing	EIVA	2	
8/27/73	K-633.3	UF6	n/a	n/a	n/a	n/a	n/a	leak in seal	EIVA	3	p. 268
8/27/73	K-1423	UF6	1532.9	3.000	46.0	1486.9	2.408E-03	defective valve	CIVA	3	p. 269, 270
8/23/74	K-413	UF6	306.6	5.000	15.3	291.2	7.312E-04	compressor ruptured	EIVA	3	p. 219-232, 244-259
8/30/74	K-1004L	UF6	n/a	n/a	n/a	n/a	n/a	cylinder not sealed	CIVA	3	p. 233-243
11/1/74	K-1131	UF6	67.6	0.711	0.5	67.1	4.542E-05	pigtail not purged	CIVA	3	p. 212-218
12/2/74	K-1004L	UF6	n/a	n/a	n/a	n/a	n/a	cracked manifold/leaking valve	EIVA	3	p. 210-211
12/19/74	K-1131	UF6	67.6	0.711	0.5	67.1	4.542E-05	instrument line ruptured	EIVA	3	p. 208-209
2/3/75	K-1004L	UF6	n/a	n/a	n/a	n/a	n/a	valve broke	EIVA	3	p. 207
3/25/75	K-402-9	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	3	p. 199-206
4/28/75	K-1420	UF6	n/a	n/a	n/a	n/a	n/a	compressor rotor		3	p. 198
5/6/75	K-33-5.2.8	UF6	6.8	n/a	n/a	n/a	n/a		EIVA	3	p. 197
5/7/75	K-902-5.2.8	UF6	n/a	n/a	n/a	n/a	n/a	compressor leaking	EIVA	3	p. 193-196
7/7/75	K-1004-C	UF6	10.1	n/a	n/a	n/a	n/a	sample tube leaking	EIVA	3	p. 187
8/3/75	K-413	UF6	n/a	n/a	n/a	n/a	n/a	pigtail not pinched off sufficiently	EIVA	3	p. 186
9/17/75	n/a	UF6	n/a	n/a	n/a	n/a	n/a	UF6 inadvertently siphoned oil into cylinder being prepared for UF6	CIVA	4	p. 149
9/27/75	K-1423	UF6	n/a	n/a	n/a	n/a	n/a	ruptured cylinder	CIVA	3	p. 171-174
10/10/75	K-31	UF6	n/a	n/a	n/a	n/a	n/a	wrong control value cut	EIVA	3	p. 168-170
3/1/76	K-33	UF6	1189	1.000	11.9	1177.1	9.315E-04	series of UF6 test releases in K-33 building to test ventilation	EIVA	4	p. 81
3/3/76	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	samples leaked	EIVA	3	p. 159
4/8/76	K-1423	UF6	n/a	n/a	n/a	n/a	n/a	leaking valve	EIVA	3	p. 141
4/20/76	K-1420	UF6	n/a	n/a	n/a	n/a	n/a			3	p. 139-140
6/5/76	K-413	UF6	135.2	5.000	6.8	128.4	3.225E-04	failed seal	EIVA	3	p. 132-138
6/14/76	602-2	UF6	n/a	n/a	n/a	n/a	n/a	compressor seals smoking	EIVA	3	p. 122
12/1/76	K-31	UF6	3.4	n/a	n/a	n/a	n/a	smoke from seats of valve	EIVA	3	p. 107-111
12/7/76	K-402-9	UF6	n/a	n/a	n/a	n/a	n/a	solidified UF6 released	EIVA	3	p. 105
12/15/76	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	vent system clogged	CIVA	3	p. 104
1/7/77	K-1210	UF6	2.0	n/a	n/a	n/a	n/a	pinched O-ring	CIVA	3	p. 103

Table E-3: K-25 Accountability Records: New Data 8-29-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference	Reference
1/12/77	K-1210	UF6	1.4	n/a	n/a	n/a	n/a	seat leak	CIVA	3	p. 102
1/16/77	K-1210	UF6	0.7	n/a	n/a	n/a	n/a	solidified UF6 in cylinder adapter	CIVA	3	p. 101
11/22/77	K-633	UF6	2.0	n/a	n/a	n/a	n/a	instrument line cracked	EIVA	3	p. 92
11/27/77	K-1131	UF6	3.4	n/a	n/a	n/a	n/a	defective control valve	EIVA	3	p. 91
12/22/77	K-1131	UF6	3.4	n/a	n/a	n/a	n/a	plug in pigtail	CIVA	3	p. 90
2/19/78	K-31-2	UF6	3.4	n/a	n/a	n/a	n/a	faulty seal	EIVA	3	p. 85-89
3/28/78	K-902-1	UF6	0.7	n/a	n/a	n/a	n/a	Change out of spool piece	EIVA	3	p. 63
5/19/78	K-310-3	UF6	n/a	n/a	n/a	n/a	n/a	seal cavity	EIVA	3	p. 62
7/23/78	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	pigtail rupture	CIVA	3	p. 61
7/24/78	K-1131	UF6	3.4	n/a	n/a	n/a	n/a	smoke emitting from plug threads	CIVA	3	p. 60
8/1/78	K-1052	UF6	n/a	n/a	n/a	n/a	n/a	ruptured bellows	EIVA	3	p. 57-59
6/5/79	K-1052	UF6	3.4	n/a	n/a	n/a	n/a	leaking trap	EIVA	3	p. 49-56
11/14/79	K-1420	UF6	3.4	n/a	n/a	n/a	n/a	smoke from rotor barrel	EIVA	3	p. 47-48
		Totals	53106.5		351.3	52707.9	0.03487				
						53059.2		The nuclide discrepancy between the sum of U-235 and U-238 and Total U is close enough resolved now through asserting building enrichments for respective time periods			

Date	Location	Material	U[g]	Wt.% U-	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Inmagic #	Reference
1/16/50	402-5	UF6	n/a	n/a	n/a	n/a	n/a	hose leaked	EIVA	1	p. 538
3/2/50	K-1301	UF4	n/a	n/a	n/a	n/a	n/a	gasket blew out	EIVA	1	p. 570
12/10/50	402-1	UF6	n/a	n/a	n/a	n/a	n/a	plugged transmitter	EIVA	1	p. 543
1/13/51	K-1131 & K-1410	UF6	n/a	n/a	n/a	n/a	n/a	cracked cold trap	EIVA	1	p. 533-535
2/5/51	310-3	UF6	n/a	n/a	n/a	n/a	n/a	coupling didn't fit properly	EIVA	1	p. 536
2/20/51	K-413	UF6	n/a	n/a	n/a	n/a	n/a	pump blew up	EIVA	1	p. 525
2/22/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	transfer connection broken	CA	1	p. 524
3/7/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	valve leaked	EIVA	1	p. 523
3/13/51	K-1401	UF6	674.5	0.711	4.8	669.7	4.532E-04	high pressure	EIVA	1	p. 522
4/2/51	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	seal	EIVA	1	p. 518
4/4/51	K-1131	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 519
4/13/51	K-1004-D rm 8	UF6	67.6	0.711	0.5	67.1	4.542E-05	blew open	CIVA	1	p. 517
4/17/51	K-101	UF6	n/a	n/a	n/a	n/a	n/a	high pressure	EIVA	1	p. 516
4/19/51	K-631	UF6	n/a	n/a	n/a	n/a	n/a	valve closure	EIVA	1	p. 515
4/25/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	leak rom ma nifold	EIVA	1	p. 514
4/28/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a	phosgene blowing from stack into building	EVA	1	p. 511
5/4/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	leak	EIVA	1	p. 509
5/5/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	cold trap	EVA	1	p. 508
5/7/51	K-1405	UF4	687.5	0.711	4.9	682.6	4.619E-04	broken bellows	EIVA	1	p. 507
5/13/51	K-312-3	UF6	n/a	n/a	n/a	n/a	n/a	unreadable		1	p. 505
5/16/51	K-131	UF6	n/a	n/a	n/a	n/a	n/a	valve	EIVA	1	p. 504
5/23/51	K-1405	UF6	4598.6	0.711	32.7	4565.9	3.090E-03	leaking from valve	EIVA	1	p. 502, 503
7/2/51	unreadable	UF6	n/a	n/a	n/a	n/a	n/a			1	p. 497
8/6/51	K-1004-A rm 19	UF6	67.6	0.711	0.5	67.1	4.542E-05	replacing stuck valve	CIVA	1	p. 495
8/25/51	402-1	UF6	n/a	n/a	n/a	n/a	n/a	ruptured pig tail	CIVA	1	p. 492
9/5/51	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	plug at cylinder head	CIVA	1	p. 491
9/19/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a	flange	EIVA	1	p. 489
9/21/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 488
9/24/51	K-306-2	UF6	n/a	n/a	n/a	n/a	n/a	flange	EIVA	1	p. 471
9/26/51	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	pump	EIVA	1	p. 482
10/5/51	K-1004-D rm 12	UF6	n/a	n/a	n/a	n/a	n/a	valve seal	EIVA	1	p. 481
10/16/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	loose connection	EIVA	1	p. 478
10/18/51	K-1401 rm 204	UF6	2298.4	0.711	16.3	2282.1	1.544E-03	cylinder leaking	CIVA	1	p. 451
11/2/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	flange	EIVA	1	p. 450
11/17/51	K-27 & K-631	UF6	n/a	n/a	n/a	n/a	n/a	seal falure/ cold trap plugged	EIVA	1	p. 442-445
11/17/51	K-631	UF6	n/a	n/a	n/a	n/a	n/a	7 or 8 release points, no info on amount or why	EIVA		p. C-18
12/7/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	flange at top of tower	EIVA	1	p. 439
12/8/51	K-1405	UF4	n/a	n/a	n/a	n/a	n/a	head on tower	EIVA	1	p. 438
12/11/51	K-1405	UF6	n/a	n/a	n/a	n/a	n/a	leak	EIVA	1	p. 437
3/6/52	K-1004-A	UF6	n/a	n/a	n/a	n/a	n/a	rupture in tubing	EIVA	1	p. 428
3/20/52	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	rupture in pump	EIVA	1	p. 425
8/14/52	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	pump head being lifted by crane	EIVA	1	p. 402
8/15/52	K-1401	UF6	268	1.119	3	265	2.223E-04	quarterly decon in K-1401	EIVA		p. C-12
9/9/52	K-131	UF6	n/a	n/a	n/a	n/a	n/a	clamp not tight	CIVA	1	p. 410-413
9/14/52	K-402-7	UF4	n/a	n/a	n/a	n/a	n/a	gasket failed	EIVA	1	p. 409
12/24/52	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	unreadable		1	p. 380

Table E-3: K-25 Accountability Records: New Data 8-29-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference	Reference
2/13/53	K-1004-J	UF4	n/a	n/a	n/a	n/a	n/a	leaky system	EIVA	1	p. 357
6/4/53	K-1004-A rm 19	UF6	2.7	0.711	0.0	2.7	1.817E-06	tube	EIVA	1	p. 333
6/16/53	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	line not cleared	EIVA	1	p. 324
6/18/53	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	spill	ESA	1	p. 330
7/14/53	K-633	UF4	n/a	n/a	n/a	n/a	n/a	pluggled line/leaking valve	EIVA	1	p. 328
8/31/53	K-1004-C rm 207	UF6	20.3	0.711	0.1	20.1	1.363E-05	cold trap broke	EIVA	1	p. 323
9/5/53	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	plugged line broke loose	EIVA	1	p. 327
9/12/53	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	area around Welsh pump	EIVA	1	p. 325
11/20/53	K-633 Test Loop	UF6	613.2	0.600	3.7	609.5	3.858E-04	operator error	ESA	1	p. 283
12/11/53	K-633	UF6	n/a	n/a	n/a	n/a	n/a	defective gasket	CIVA	1	p. 322
12/29/53	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	discharge head removed from compressor	EIVA	1	p. 313
2/3/54	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	head removed from compressor	EIVA	1	p. 307, 308
2/5/54	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	instrument line burst	EIVA	1	p. 306
4/6/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a			1	p. 301
4/10/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	cylinder leak	CD	1	p. 300
5/10/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	cold trap	EIVA	1	p. 304
5/11/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	tower area	EVA	1	p. 305
5/12/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 303
5/18/54	K-1131	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	1	p. 302
6/19/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Valve failure	EIVA	1	p. 297
7/29/54	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	defective valve	EIVA	1	p. 281
8/18/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	cylinder valve	CIVA	1	p. 280
9/17/54	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	valve bonnet backed out	EIVA	1	p. 277
9/27/54	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	seal failure	EIVA	1	p. 275, 276
10/30/54	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	compressor	EIVA	1	p. 272
1/19/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Assembly loosened in shell	EIVA	1	p. 268
2/3/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Attempting to remove rotor	EIVA	1	p. 264
2/10/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	While applying heat to shell, gas was released	EIVA	1	p. 262, 263
3/15/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Stator broke loose	EIVA	1	p. 254-259
6/9/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Disassembling compressor	EIVA	1	p. 241-244
6/10/55	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Dismantling compressor	EIVA	1	p. 239, 240
8/31/55	K-301-1 Cell 4	UF6	119.0	15.000	17.8	101.1	8.168E-04	valving error	ESA	1	p. 198
9/28/55	Vault 15-A	UF6	2.0	2.000	0.0	2.0	2.347E-06	release from corroded drum	DD	1	p. 198
9/28/55	Vault 16-A	UF6	153.0	2.000	3.1	149.9	1.796E-04	release from corroded drum	DD	1	p. 198
11/30/55	Vault 15-A	UF6	1.0	2.000	0.0	1.0	1.174E-06	Corroded drum	DD	1	p. 186
12/4/55	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Ruptured bellows on product cylinder valve gave 3 - 4 min. release	CIVA	1	p. 190
12/20/55	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Seal failed on pump; 2 hr. release resulted in high air activity	EIVA	1	p. 187
12/24/55	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Release due to valve failure	EIVA	1	p. 185
3/1/56	Vault 26-A	UF6	10.0	2.000	0.2	9.8	1.174E-05		DD	1	p. 179
3/15/56	Vault 16-A	UF6	171.0	2.000	3.4	167.6	2.007E-04	Leakage due to corroded drums	DD	1	p. 178
4/4/56	Vault 15-A	UF6	1748.0	2.000	35.0	1713.0	2.051E-03	Leakage due to corroded drums	DD	1	p. 157, 176
4/9/56	Vault 16-A	UF6	5026.0	2.000	100.5	4925.5	5.899E-03	Leakage due to corroded drums	DD	1	p. 157,171
4/9/56	Vault 16-A	UF6	1930.0	2.000	38.6	1891.4	2.265E-03	Leakage due to corroded drums	DD	1	p. 157, 1897
4/9/56	Vault 16-A	UF6	11885.0	2.000	237.7	11647.3	1.395E-02	Leakage due to corroded drums	DD	1	p. 157, 169
4/20/56	Vault 16-A	UF6	11.0	n/a	n/a	n/a	n/a	Dropped carboy; most recovered	DD	1	p. 157, 168
4/20/56	K-304	UF6	n/a	n/a	n/a	n/a	n/a	209 grams of "X" material which was alpha radioactive; recovered most of material	spilled on road	1	p. 167
5/7/56	K-1131	UF4	n/a	n/a	n/a	n/a	n/a	Bellows leaked and UF4 powder was blown into the air; 2 min. release but no 'smoking' noticed	ESA	1	p. 161
5/25/56	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	Valve on trap failed to seat; 12 min. release	ESA	1	p. 158
8/2/56	"F" avenue, 14th a	UF6	n/a	n/a	n/a	n/a	n/a	Contaminated oil leaked onto streets during transport of pump		1	p. 144
8/15/56	K-1131	UF6	30672	0.300	92	30580	1.577E-02	normal vent emissions from stack	ESA		p. C-11
2/4/57	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	5 min. release when valve was removed	EIVA	1	p. 111
4/12/57	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	Receiver wall burned through releasing UF6	EIVA	1	p. 104
5/27/57	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	Small release when seal failed	EIVA	1	p. 98
6/1/57	K-303-3	UF6	n/a	n/a	n/a	n/a	n/a	2 min. release when attempting to remove UF6 plug	EIVA	1	p. 97
6/11/57	K-1401	UF6	n/a	n/a	n/a	n/a	n/a	Release of short duration occurred when dismantling compressor	EIVA	1	p. 95
8/16/57	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Bellows ruptured when valve was opened, 5 min gas release	EIVA	1	p. 89
8/21/57	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Pump seal failure led to gas release for 10 min.	EIVA	1	p. 88
8/24/57	K-1420	UF6	n/a	n/a	n/a	n/a	n/a	Large release trapped process gas escaped	EIVA	1	p. 85
10/28/57	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	Entrapped UF6 in line between cleanup reactor and cold traps vaporized when opened	EIVA	1	p. 79
1/13/58	K-902.4	UF6	307	1.303	4	303	2.766E-04		EIVA		p. C-19
3/11/58	K-413	UF6	n/a	n/a	n/a	n/a	n/a	Packing gland on Beach-Russ pump failed	EIVA	1	p. 55
4/9/58	K-902-4	UF6	n/a	n/a	n/a	n/a	n/a	Small release during seal removal	EIVA	1	p. 33
5/13/58	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	Seal failed, small release	EIVA	1	p. 46
6/1/58	K-306-7	UF6	n/a	n/a	n/a	n/a	n/a	Valve bellows on cylinder ruptured	CIVA	1	p. 33
6/25/58	K-402-3.6	UF6	205	10.244	21	184	9.531E-04	Line recorder line opened, due to wear, inside cell	EIVA		p. C-19
9/5/58	K-1131 / K-1410	UF4	n/a	n/a	n/a	n/a	n/a	UF4 spill on road between K-1131 and K-1410		1	p. 23
9/24/58	K-1413	UF6	n/a	n/a	n/a	n/a	n/a	UF6 cloud released directly to atmosphere	CA	1	p. 16

Table E-3: K-25 Accountability Records: New Data 8-29-96

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference	Reference
7/1/69	K-1131	UF6	153	0.200	0	153	7.285E-05	leak in air system vented to atmosphere	EIVA	2	
8/1/69	K-1423	UF6	920	0.711	7	913	6.181E-04	During feed cylinder operation, difficulty in obtaining a sample; several cold trap evacuations resulted in UF6 discharge	ESA	2	
9/1/69	K-1423	UF6	613.0	1.457	9	604.0	5.889E-04	During cylinder sampling operation the evacuation valve remained open thus resulting in a UF6 release	CIVA	2	
8/15/70	n/a	n/a	n/a	n/a	n/a	n/a	n/a	just one release noted, no other information	n/a	4	p. E-1
2/1/72		UF6	7473.0	0.711	53	7420.0	5.021E-03	UF6 used in cell out-leakage testing	EIVA	2	
8/27/73	K-633.3	UF6	n/a	n/a	n/a	n/a	n/a	leak in seal	EIVA	3	p. 268
8/27/73	K-1423	UF6	1532.9	3.000	46.0	1486.9	2.408E-03	defective valve	CIVA	3	p. 269, 270
8/23/74	K-413	UF6	306.6	5.000	15.3	291.2	7.312E-04	compressor ruptured	EIVA	3	p. 219-232, 244-259
8/30/74	K-1004L	UF6	n/a	n/a	n/a	n/a	n/a	cylinder not sealed	CIVA	3	p. 233-243
11/1/74	K-1131	UF6	67.6	0.711	0.5	67.1	4.542E-05	pigtail not purged	CIVA	3	p. 212-218
12/2/74	K-1004L	UF6	n/a	n/a	n/a	n/a	n/a	cracked manifold/leaking valve	EIVA	3	p. 210-211
12/19/74	K-1131	UF6	67.6	0.711	0.5	67.1	4.542E-05	instrument line ruptured	EIVA	3	p. 208-209
2/3/75	K-1004L	UF6	n/a	n/a	n/a	n/a	n/a	valve broke	EIVA	3	p. 207
3/25/75	K-402-9	UF6	n/a	n/a	n/a	n/a	n/a		EIVA	3	p. 199-206
4/28/75	K-1420	UF6	n/a	n/a	n/a	n/a	n/a	compressor rotor		3	p. 198
5/6/75	K-33-5.2.8	UF6	6.8	n/a	n/a	n/a	n/a		EIVA	3	p. 197
5/7/75	K-902-5.2.8	UF6	n/a	n/a	n/a	n/a	n/a	compressor leaking	EIVA	3	p. 193-196
7/7/75	K-1004-C	UF6	10.1	n/a	n/a	n/a	n/a	sample tube leaking	EIVA	3	p. 187
8/3/75	K-413	UF6	n/a	n/a	n/a	n/a	n/a	pigtail not pinched off sufficiently	EIVA	3	p. 186
9/17/75	n/a	UF6	n/a	n/a	n/a	n/a	n/a	UF6 inadvertently siphoned oil into cylinder being prepared for UF6	CIVA	3	p. 149
9/27/75	K-1423	UF6	n/a	n/a	n/a	n/a	n/a	ruptured cylinder	CIVA	3	p. 171-174
10/10/75	K-31	UF6	n/a	n/a	n/a	n/a	n/a	wrong control value cut	EIVA	3	p. 168-170
3/1/76	K-33	UF6	1189	1.000	11.9	1177.1	9.315E-04	series of UF6 test releases in K-33 building to test ventilation	EIVA	4	p. 81
3/3/76	K-1004-L	UF6	n/a	n/a	n/a	n/a	n/a	samples leaked	EIVA	3	p. 159
4/8/76	K-1423	UF6	n/a	n/a	n/a	n/a	n/a	leaking valve	EIVA	3	p. 141
4/20/76	K-1420	UF6	n/a	n/a	n/a	n/a	n/a			3	p. 139-140
6/5/76	K-413	UF6	135.2	5.000	6.8	128.4	3.225E-04	failed seal	EIVA	3	p. 132-138
6/14/76	602-2	UF6	n/a	n/a	n/a	n/a	n/a	compressor seals smoking	EIVA	3	p. 122
12/1/76	K-31	UF6	3.4	n/a	n/a	n/a	n/a	smoke from seats of valve	EIVA	3	p. 107-111
12/7/76	K-402-9	UF6	n/a	n/a	n/a	n/a	n/a	solidified UF6 released	EIVA	3	p. 105
12/15/76	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	vent system clogged	CIVA	3	p. 104
1/7/77	K-1210	UF6	2.0	n/a	n/a	n/a	n/a	pinched O-ring	CIVA	3	p. 103
1/12/77	K-1210	UF6	1.4	n/a	n/a	n/a	n/a	seat leak	CIVA	3	p. 102
1/16/77	K-1210	UF6	0.7	n/a	n/a	n/a	n/a	solidified UF6 in cylinder adapter	CIVA	3	p. 101
11/22/77	K-633	UF6	2.0	n/a	n/a	n/a	n/a	instrument line cracked	EIVA	3	p. 92
11/27/77	K-1131	UF6	3.4	n/a	n/a	n/a	n/a	defective control valve	EIVA	3	p. 91
12/22/77	K-1131	UF6	3.4	n/a	n/a	n/a	n/a	plug in pigtail	CIVA	3	p. 90
2/19/78	K-31-2	UF6	3.4	n/a	n/a	n/a	n/a	faulty seal	EIVA	3	p. 85-89
3/28/78	K-902-1	UF6	0.7	n/a	n/a	n/a	n/a	Change out of spool piece	EIVA	3	p. 63
5/19/78	K-310-3	UF6	n/a	n/a	n/a	n/a	n/a	seal cavity	EIVA	3	p. 62
7/23/78	K-1131	UF6	n/a	n/a	n/a	n/a	n/a	pigtail rupture	CIVA	3	p. 61
7/24/78	K-1131	UF6	3.4	n/a	n/a	n/a	n/a	smoke emitting from plug threads	CIVA	3	p. 60
8/1/78	K-1052	UF6	n/a	n/a	n/a	n/a	n/a	ruptured bellows	EIVA	3	p. 57-59
6/5/79	K-1052	UF6	3.4	n/a	n/a	n/a	n/a	leaking trap	EIVA	3	p. 49-56
11/14/79	K-1420	UF6	3.4	n/a	n/a	n/a	n/a	smoke from rotor barrel	EIVA	3	p. 47-48
12/11/79	K-1131	UF6	169.0	0.711	1.2	167.8	1.136E-04	faulty valve	CD	3	p. 46
		Totals	74212.5		771.0	73383.2	0.05954				
						74154.2		The nuclide discrepancy between the sum of U-235 and U-238 and Total U is close enough resolved now through asserting building enrichments for respective time periods			

1 Author Unknown 1958. Material Releases 1950-1958; 1945-1949; 1959-1964. K/EM-461; K/CR-743; K/CR-744. ChemRisk Repository No.2886
2 UCC 1968-1972. Union Carbide Company. Request for Approved Inventory Write-Offs. KX-10022. ChemRisk Repository No. 2885
3 UCC 1973-1982. Union Carbide Company. UF6 Releases. Document Number Unknown. ChemRisk Repository No. 2884
4 UCC 1960-1976. Extract from Oak Ridge Gaseous Diffusion Plant Quarterly Report. ChemRisk Repository No. 2824

Table E-4: K-25 Accountabilty Records: New Data 11-6-97

Date	Location	Material	U[g]	Wt.% U-235	U-235 [g]	U-238 [g]	Ci	Description	Pathway	Reference
11/28/44	S-50	UF6	58269	0.711	414.3	57851.0	3.92E-02	break in link line from No. 1 scale tank	EIVA	1
3/1/45	S-50	UF6	899774.4	0.711	6397.4	893320.3	6.05E-01	reported losses	EIVA	2
4/1/45	S-50	UF6	1233474.5	0.711	8770.0	1224626.8	8.29E-01	reported losses	EIVA	2
5/1/45	S-50	UF6	367475.4	0.711	2612.8	364839.5	2.47E-01	reported losses	EIVA	2
6/1/45	S-50	UF6	366124.4	0.711	2603.1	363498.2	2.46E-01	reported losses	EIVA	2
7/1/45	S-50	UF6	166850.1	0.711	1186.3	165653.3	1.12E-01	reported losses	EIVA	2
2/24/60	K-1131	UF6	214960	0.711	1528	213418.1	1.44E-01	ruptured heating coil in "E" cold trap	EIVA	3
5/7/60	K-1131	UF6	184003	0.650	1196.0	182796.9	1.19E-01	rupture of steam heating coil during drainage of the "F" cold trap	EIVA	3
1/1/93	K-1004-L	n/a	86.9	0.692	0.6	86.3	5.93E-05	releases from lab hoods	ESA	4
1/1/93	TSCA	n/a	11984.1	0.657	78.7	11904.8	7.97E-03	releases from TSCA	ESA	4
1/1/93	K-1008-C	n/a	1.8	0.670	0.01	1.8	1.19E-06	releases from respirator hoods	ESA	4
1/1/93	K-1435	n/a	185.8	0.673	1.3	184.5	1.23E-04	(atmospheric) releases from waste feed tanks	ESA	4
1/1/94	K-1004	n/a	154.1	0.712	1.1	153.0	1.03E-04	releases from lab hoods	ESA	5
1/1/94	K-1006	n/a	14.4	0.706	0.1	14.3	9.62E-06	releases from lab hoods	ESA	5
1/1/94	K-1004-L	n/a	138.2	0.710	1.0	137.2	9.26E-05	releases from lab hoods	ESA	5
1/1/94	TSCA	n/a	5965.5	0.714	42.6	5922.6	4.04E-03	releases from TSCA	ESA	5
1/1/94	K-1435	n/a	179.0	0.711	1.3	177.7	1.20E-04	(atmospheric) releases from waste feed tanks	ESA	5
1/1/94	K-1430-A	n/a	1211.0	0.711	8.6	1202.4	4.41E-04	releases from lab hoods	ESA	5
1/1/94	K-31	n/a	1000.4	2.999	30.0	970.2	1.57E-03	removal of cascade equipment	EIVA	5

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APPENDIX F

CHARACTERIZATION OF THE PURGE CASCADE AND UNCERTAINTIES IN PURGE CASCADE MONITORING

- **Monitoring Methods for Purge Cascade and a Typical Flow Diagram of Light Diluents Passed Through the Purge Cascade (1945 to 1964)**
- **Sample Calculations for Estimating Releases from the Purge Cascade**

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F.1 HISTORY OF THE PURGE CASCADE

In mid-1945, the purge cascade was in three sections in the K-25 building– K-312-1, K-312-2, and K-312-3. Each section was a complete plant for the separation of light diluents from UF_6. Normally, one or two sections were operating; the third was needed only occasionally when purging requirements were severe, or when it became necessary to shut down an operating section for repairs. By the mid-1950s, the K-311-1 section in the K-25 building began operation as a "side purge" to increase purge capacity and help remove heavier purge gases, such as coolant vapor and ClF_3 used in conditioning and cleaning.

In 1964, the K-25 mission shifted from production of weapons grade, highly enriched (>90% ^{235}U) uranium to low enriched uranium (<5% ^{235}U) for the nuclear power industry. At that point, only the K-311-1 section was needed for light diluent purging. Later in the mid-1970s, to comply with stricter federal air release regulations, a new purge facility in the K-27 building was placed in operation.

By the late 1970s, a new purge cascade had been constructed in the K-402-9 section of the K-27 building. The new purge cascade included an alkaline scrubber to remove gases emitted from the diffusion process. The gas stream, containing F_2, UF_6, ClF_3, TeF_8, and their reaction products, was mixed with air from the ejectors and passed through the scrubber, where contact with a spray of potassium hydroxide (KOH) solution removed toxic gases. The KOH solution, which absorbed toxic compounds and a large quantity of CO_2 from the ejectors, was circulated into a storage tank for containment. A continuous circulation of the solution from the tank, through the bag filters, and back to the scrubber was performed to remove undissolved solids. Solids were periodically removed from the bag filters and transferred to waste containers (McCall 1979).

The K-402-9 section began operation as the purge cascade in 1976 with NaF traps and KOH scrubbers in place, greatly reducing uranium releases. In 1979, the K-402-8 section began operation as a companion side purge. All purging ceased in 1985, when diffusion operations at K-25 were shut down.

F.2 PURGE CASCADE MONITORING METHODS

Analysis of process gas in the purge cascade was complicated, because UF_6 concentration varied greatly from one end of the cascade to the other. Near the bottom of the cascade the process stream consisted of essentially pure UF_6, whereas at the cascade top the stream consisted of light gases containing only traces of UF_6.

To monitor traces of UF_6 in the purge cascade, the "space recorder" was developed. The principal component of the space recorder was an ionization chamber, commonly referred to as the "signal can". The signal can measured specific radioactivity of the gas present. Since uranium isotopes in UF_6 are alpha emitters, this method provided a convenient means for measuring UF_6 content of gas samples. The space recorder could detect mole fractions of UF_6 in the light gas purge on the order of 10^{-6}.

The uranium in UF_6 decayed with the emission high energy alpha particles. The decay rate depended upon the isotopic composition of the gas, since all uranium isotopes emit alpha particles with different half lives. The alpha particles had a specific range of travel, inversely proportional to the pressure. Measuring the ionic current generated by the alpha particles in the signal can determined the number of particles present and hence a determination of the UF_6 concentration.

To detect low concentrations of UF_6, it was necessary to employ a signal can having an internal diameter of 12 inches and an inside length of 24 inches. Although the sensitivity could be improved by using a higher pressure, the available pumps precluded a pressure greater than 10 psia. Because of the corrosive nature of UF_6 and consequent danger of high background, all metal surfaces were nickel. The collector wire, 0.025 inch in diameter, was mounted along the axis of the can and connected to the pre-amplifier on the cover of the can through a vacuum-tight plastic disk. A grid of a cage approximately 20 inches long and 8 inches in diameter was mounted concentric with the collector wire. The cage was constructed of nickel wire 0.0031 inch in diameter spaced 1 inch apart. The signal can was at ground potential, the collector wire a few millivolts above ground, and the cage several hundred volts above ground. All positive ions formed within the grid were drawn to the central collector wire. If the signal can operated at a pressure of more than 10 psia, none of the alpha particles originating from corrosion products on the inside wall of the can have sufficient range to penetrate the grid assembly. Hence, background ionization current in the device would be due only to alpha particles originating on the grid structure or collector wire and to beta particles.

The output current of the pre-amplifier was fed to an amplifier circuit and subsequently to a single point strip chart recorder. The strip chart readings were monitored each shift and recorded in the foreman*s logbook.

The purge system at the K-402-9 section during the mid-1970s included a scrubber system to capture and retain materials in the exhaust purge. Exhaust gas was analyzed for fluorine, chlorine, uranium, and technetium. The sampling train for gas sampling is shown in Figure F-1. Gas was pulled through two Boyce-Thompson collectors containing a KOH solution, to which glass beads were added. The beads raised the contact surface of the gas sample with the liquid, increasing sampling efficiency. Sampling was conducted for 24 hour periods at flow rates yielding isokinetic velocity through the sampling probe. (McCall 1979)

The initial purge cascade sampling location was close to the outlet of the scrubber. Problems with liquid carry-over from the scrubber, caused the sampling location to be moved to the end of the exhaust line as shown in Figure F-2. The vacuum from the exhaust blower was used to transfer gas through the auxiliary sampling line, to take a sample. This sampling near the exhaust stack exit minimized liquid carry-over (McCall 1979).

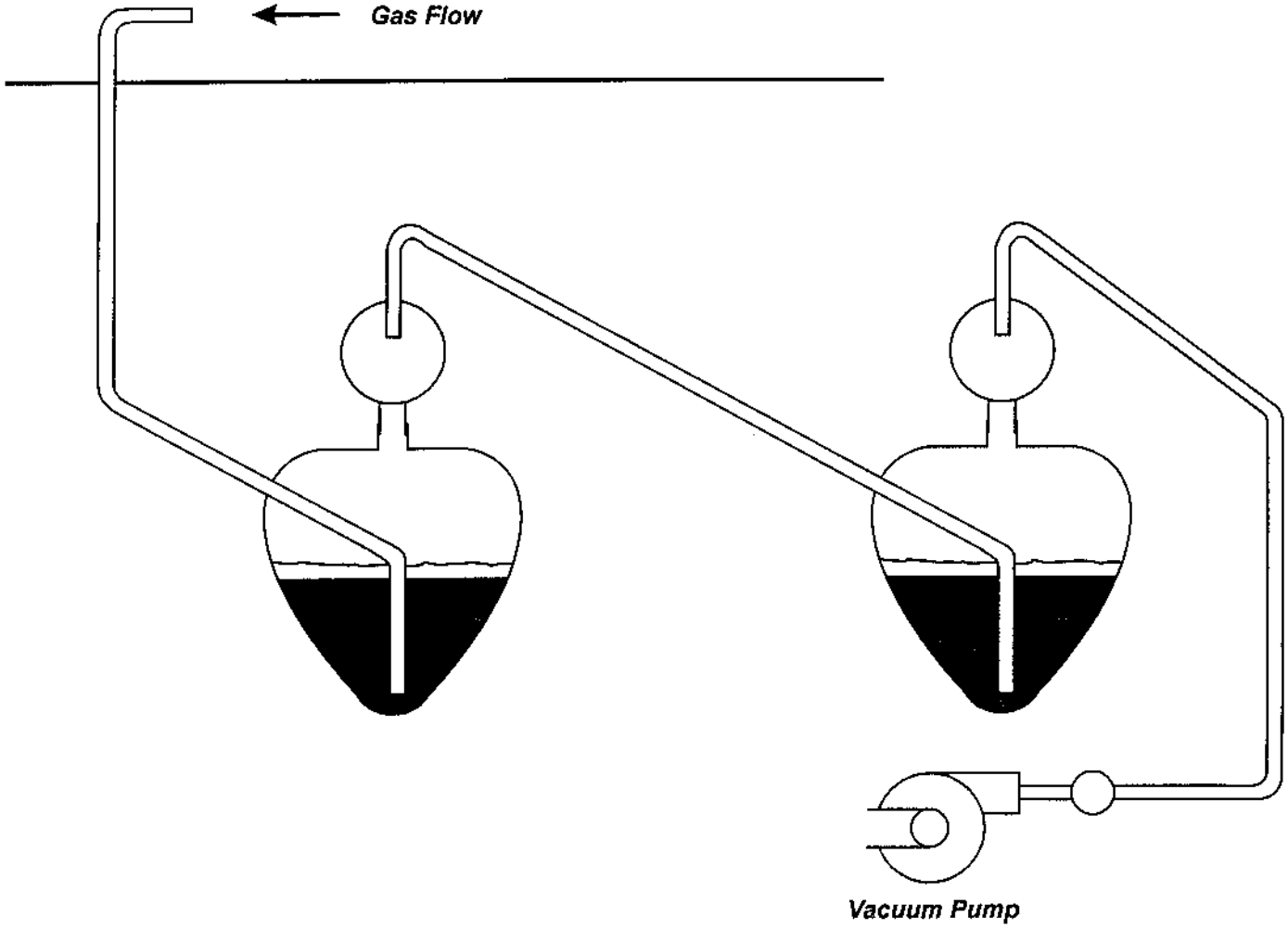

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FIGURE F-1
GAS SAMPLING TRAIN

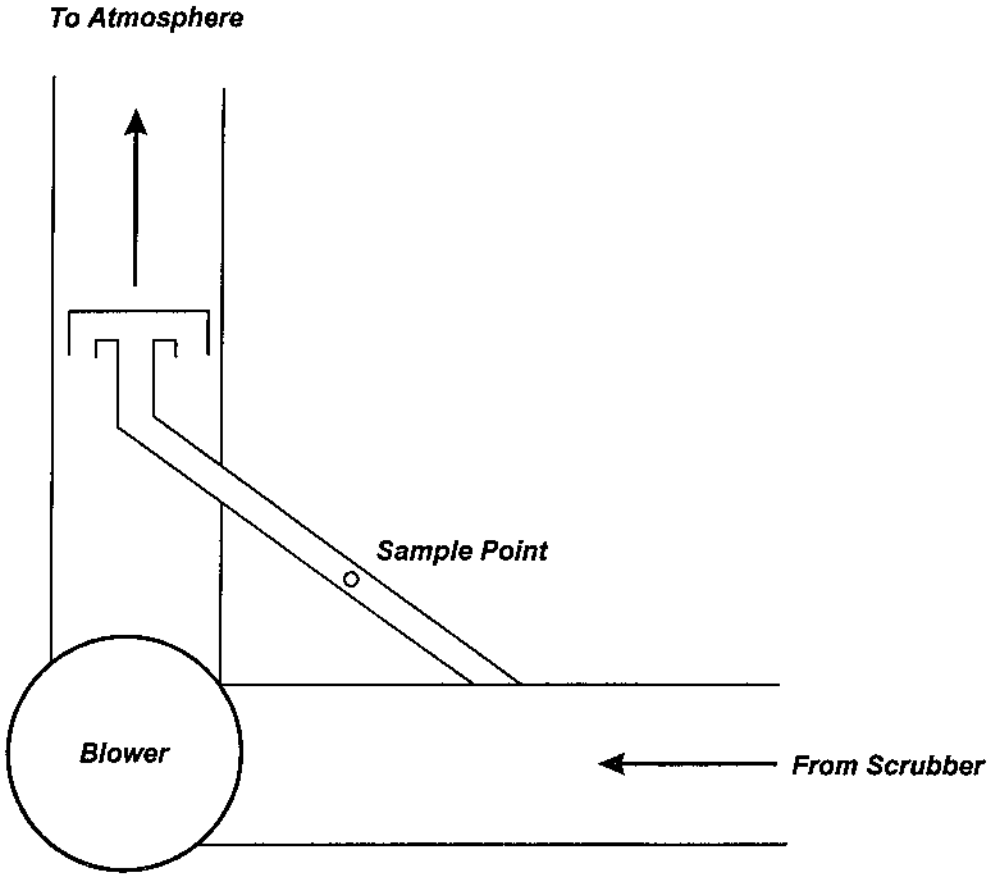

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FIGURE F-2
EXHAUST GAS SAMPLING POINT

F.3 SAMPLE CALCULATIONS FOR ASSESSING THE CASCADE AND OTHER K-25 AND Y-12 RELEASES

Data sheets containing the record of the daily purge rates for the time periods analyzed were transferred to spreadsheets. The volume of gas purged each day and its UF_6 concentration was used to compute daily volumetric flow of UF_6 released. The daily flow of UF_6 was summed to estimate the total volume of UF_6 vented during the month. The mass of UF_6 released each month in the purge cascade (m) was then derived from this volume at standard conditions using the modified van der Waals real gas equation as given in Equation 1 (Ackley and Magnuson 1951).

$$m = \frac{P(1 - AP)V}{RT} \qquad \textit{Equation 1}$$

where P is the pressure of the gas,
A is the temperature-dependent van der Waals coefficient for UF_6,
V is the volume of the gas,
R is the UF_6 gas constant, and
T is the temperature of the gas.

The activity of UF_6 released each month in the purge cascade was computed by multiplying the grams of UF_6 by the specific activity of UF_6 at the assumed ^{235}U enrichment level. The "effective" specific activity of a mixture of $^{234}UF_6$, $^{235}UF_6$, and $^{238}UF_6$ (as found in the purge cascade effluent) follows Equation 2 (Rich et al. 1988).

$$S = (0.4 - 0.38E - 0.0034E^2) \times 10^{-6} \quad Ci/g \qquad \textit{Equation 2}$$

where E is the percent ^{235}U by weight. Eq. 2 is fitted to the experimental data in Figure F-3. The contribution to the total "effective" activity of each isotope of uranium was determined from the graph presented in Figure F-4 and used to determine the activity of each isotope. The mass of ^{234}U, ^{235}U, and ^{238}U in the purge effluent could then be calculated from its activity and theoretical specific activity as given by Equation 3.

$$m_i = \frac{A_i}{S_i} \qquad \textit{Equation 3}$$

where A_i is the activity of the radioisotope, and
S_i is the specific activity of the radioisotope.

The results of the isotopic mass calculations were compared to the mass calculations for UF_6 using Eq. 1 in order to determine how appropriate the values selected from Fig. 2 were.

The theoretical specific activity of each uranium isotope is calculated by Equation 4.

$$S_i = \frac{\lambda_i N_A}{M_i} \qquad \textit{Equation 4}$$

where l_i is the decay constant of the radioisotope,
N_A is Avogadro*s Number, and
M is the atomic weight of the radioisotope.

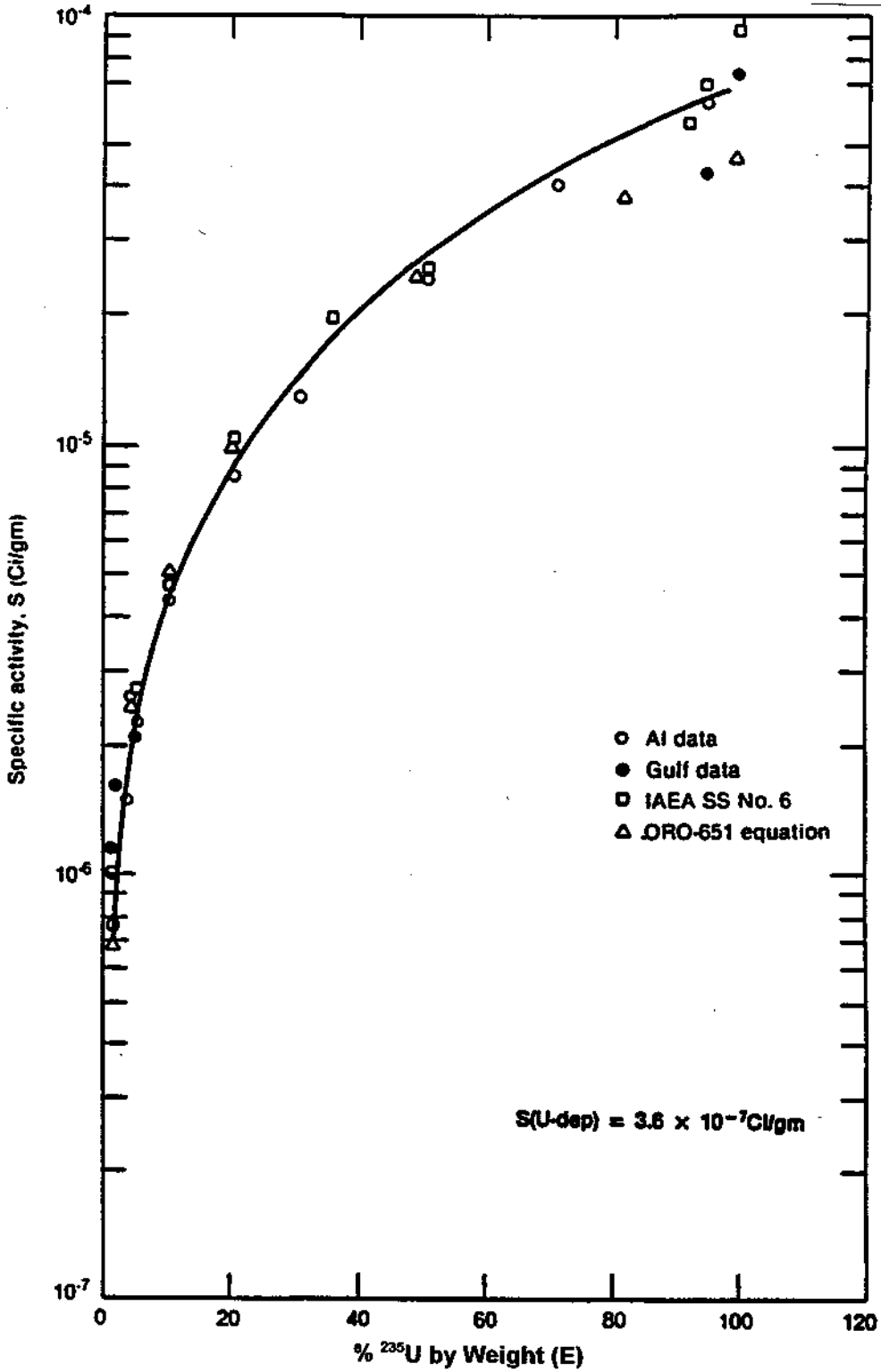

Figure F-3: Specific Activity for Mixtures of ^{238}U, ^{234}U, and ^{235}U

(Adopted from Health Physics Manual of Good Practices for Uranium Facilities, EGG-2530. June 1988)

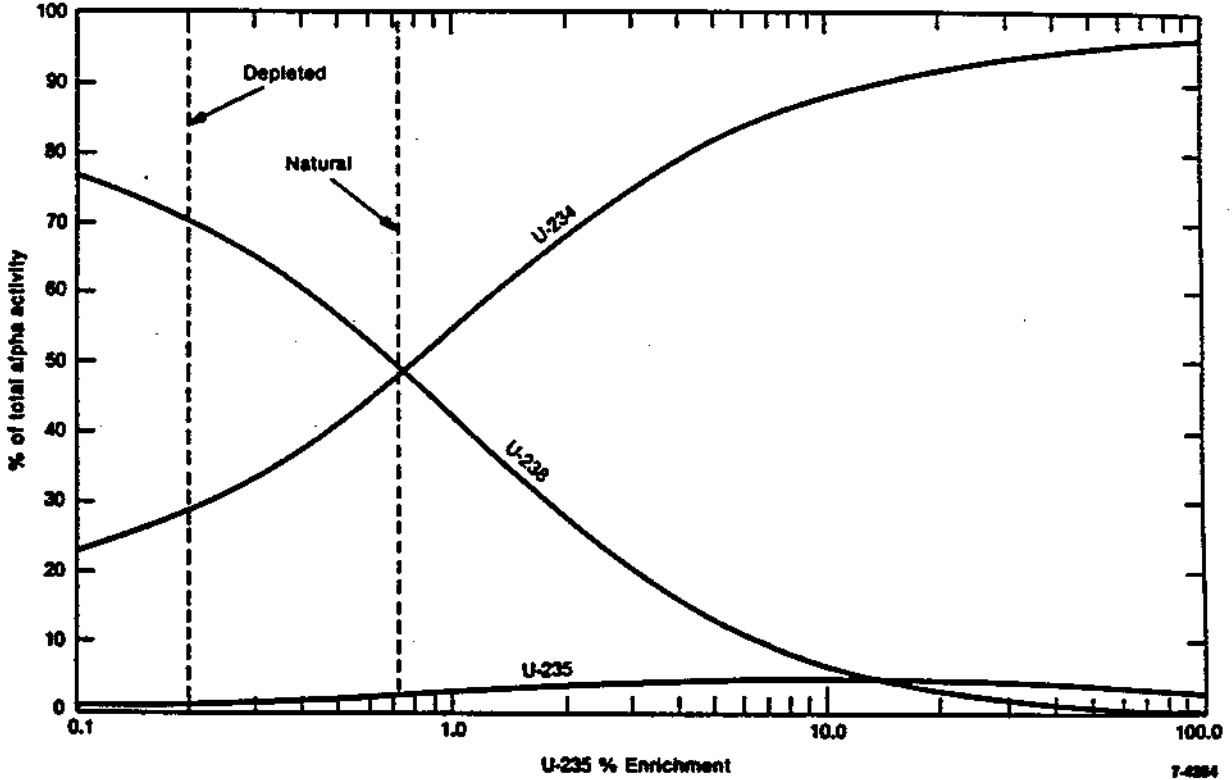

Figure F-4: Percent of Total Radioactivity by Isotope vs. % Weight ^{235}U Enrichment Calculated from $S=(0.4 + 0.38E + 0.0034E^2)x10^{-6}$ Ci/g (gaseous diffusion process)

(Adopted from Health Physics Manual of Good Practices for Uranium Facilities, EGG-2530. June 1988)

F.4 UNCERTAINTY IN PURGE CASCADE MONITORING

The space recorder operating manual states that, in measurement of UF_6 concentration, the presence of background signal raised the lower limit of detection for UF_6. The background was due to a number of causes:

1) All materials contain traces of radioactive elements, and the materials from which the signal cans were constructed were no exception.

2) The passage through the signal can of gamma rays from the surroundings and cosmic rays produced small residual ionization.

3) The radioactive disintegration of uranium results in the formation of actinon and radon. The presence of actinon in the signal can was shown to be negligible in regard to background, but the concentration of radon daughter products would gradually increase with time. After a number of years of operation, the rising concentration might impact performance of the instrument.

4) The presence of UF_6 in the signal can resulted in deposits of radioactive compounds on the internal surface of the can, giving rise to the most serious source of background. The chemical reaction of UF_6 with the surfaces of the can or any other substances present (i.e. water vapor) produced uranium compounds that emitted alpha particles. The grid structure sought to minimize the effect, but did not eliminate it completely. Additionally, the radioactive decay of uranium formed beta and gamma emitters that deposited on the walls of the signal can.

Space recorder background varied with the pressure, and was greatest at 2.5 psia. At this pressure, the background consisted mainly of alpha particles from uranium products on the signal can wall. However, at the normal operating pressure of 10 psia, the background rose continually, even though chemical reaction of UF_6 with the wall had ceased. It was assumed that this rising background at 10 psia was due to beta particles, gammas rays, or both from successive radioactive disintegrations of the decay products of ^{238}U deposited on the walls. These beta and gamma radiations had greater range inside the signal can than the alpha particles and would thus enter the collecting region inside the cage.

From November 1945 through February 1946, a study was conducted by the Process Development Department of the K-25 Engineering Division to determine the accuracy of the space recorders. Laboratory analytical results were compared with space recorder data, and the results indicated that the precision of the space recorder was satisfactory. However, it was stated in the same report that both laboratory analysis and space recorder results are low because of the possibility of UF_6 absorption on the inside surface of the long copper tubing leading to the space recorder and the laboratory sampling manifold. Apparently there was a trace indicator connected to the line at K-312-2 to measure UF_6 concentration before the process gas passed through the sampling lines (Smiley 1945). It was later reported that large errors in space recorder readings caused by faulty operation would be easily detectable by laboratory

analysis. The daily lab analysis that began in November 1945 was discontinued in February 1946. The report also stated that whenever space recorder data was questionable, laboratory sampling and analysis would be used as verification of reported concentration (Smiley 1945).

The K-25 Site Environmental Program was reviewed from June 15-17, 1982 by the Union Carbide Health, Safety, and Environmental Affairs office (Abee et al. 1982). The team suggested that the sampling line to the purge cascade sampler be as short as practicable to enhance the representativeness of the sample collected. It was observed that the sampling line from the exhaust duct sampling port to the sampling equipment was about 20-25 feet in length. The team indicated that such a long sampling line can result in absorption and perhaps subsequent release of material, and that the sample collected would not represent the material being released.

In response, K-25 relocated the sample probes on the purge cascade airborne effluent sampling system. A second sampler was installed to improve system reliability. Shortening of the sample line was evaluated and determined to be impractical. The K-25 staff indicated that sample bias was negligible because the sample line was thoroughly cleaned each time a sample was removed (daily). Also, K-25 indicated that a new purge cascade effluent scrubber system was to be installed during fiscal year 1982, and the new system would include a new sampler.

APPENDIX G

THE LIQUID THERMAL DIFFUSION PROCESS

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APPENDIX G: THE LIQUID THERMAL DIFFUSION PROCESS

The S-50 liquid thermal diffusion plant operated for 12 months from September 1944 to September 1945. It was based on an enrichment concept proposed by P. H. Abelson while working for the Naval Research Laboratory during the war (Fox 1945a). The thermal diffusion process, originally conceived for use as a solvent separation proces, separates molecules of different densities by subjecting a thin film of gas or liquid present between vertical walls to high heat transfer. This is accomplished by holding one of the vertical walls held at a cold temperature and the other held at a hot temperature. Under these conditions, convection currents are established that cause upward flow of the fluid along the hot wall and downward flow along the cold wall. At the same time, the lighter molecules tend to move towards the hot wall while the heavier molecules move to the colder one, creating the conditions needed to enrich a fluid stream in the desired weight molecule. At S-50, the vertical walls were created by nesting 48 foot long tubes of nickel, copper and iron. The inner nickel tube, with an outside diameter of 1.645 inches, was heated with wet process steam at 1000 psia and 550 °F. The thin gap was formed between the nickel tube and middle copper tube which had an inside diameter of 1.685 inches. The gap was filled on a batch charge basis with uranium hexafluoride (UF_6) at pressures up to 1500 psia. The cooling for the copper pipe was provided by encasing the copper pipe with an outer steel pipe, about 4 ½ inches in diameter, which was cooled with 150 °F water (warm enough to prevent the UF_6 from solidifying). Laboratory experiments and a pilot plant were successful in doubling the percent abundance of the ^{235}U isotope over that found in natural uranium.

The S-50 plant was built on about 37 acres of land adjacent to the K-25 Power House, which provided the plant's process steam. Construction began on June 6, 1944 and took 75 days to complete. Partial operations commenced on 9/17/44 (the first columns were available for conditioning only two days earlier) while construction of the other buildings at the site was still being completed (Fox 1945a). The plant was operated for nearly 12 months, being shut down on September 9, 1945. The buildings were demolished and buried shortly thereafter. Some narratives of the operational history assert 10 months of operation, which presumably reflects the period from first product withdrawal to shutdown.

The intended purpose of the S-50 plant was to produce low-enrichment uranium, initially as a feed material to the Y-12 plant's electromagnetic enrichment process, and later as a feed for the K-25 site gaseous diffusion plant. Operations were terminated early in part due to the rapid growth of the output from the gaseous diffusion plant and perhaps in part due to unsustainable losses suffered during the ten to twelve month operating history. Losses from the S-50 plant are thought to represent a significant fraction of the total uranium releases for the K-25/S-50 complex. These losses have not been included in prior DOE/K-25 summaries. Although S-50 was physically located at the K-25 site, it was not considered part of K-25 operations administratively. The S-50 plant is one of the major undocumented (or poorly documented) source of historic uranium emissions from the Oak Ridge Reservation.

The basic process module at the S-50 Plant was a rack consisting of two rows of 51 columns of tubes (S-50 1945). There were 21 racks in total, for 2142 columns. They were located in the main building, which was called the Process Building, and designated F-01. The process tubes were 48 feet long. The 21 racks were divided into 3 sections, each of which was supplied with a separate steam supply. A

transfer room and a control room was provided for each pair of racks. These were located on a mezzanine level in the main process building. The Operations Division was responsible for operating the first 20 racks. Since there was an odd number of racks, the 21st rack was provided with its own transfer and control room and operationally was under the direction of the Technical Division. This 21st rack was used for experimental purposes for process refinement as well as production.

Releases of uranium from the S-50 plant to the atmosphere would occur from planned routine emissions, unplanned chronic releases and large episodic events. The difference between chronic and episodic is drawn in part because the operational conditions appear to have resulted in chronic, small leaks from many sources. Examples of routine planned emissions include the practice of conditioning the columns by allowing eight pounds of UF_6 to passivate or react with the tubing surface. Current documentation from K-25 environmental activities describes this process as bizarre (LMES 1995). Following conditioning, the residual UF_6 , which might be a large fraction of the UF_6 used, was allowed to vent to the atmosphere. Transfers of UF_6 to and from the process equipment were also problematic. Examples of unplanned chronic releases are piping and connection failures which, given the temperature and pressure of the UF_6, were difficult to arrest. There was a complex piping system interconnecting the 2142 triple nested pipes with water, steam and UF_6. From various accounts of the process, it appears that failures such as this occurred on a greater than daily frequency, perhaps upwards of a dozen times on a bad day. Large episodic events occurred as a result of significant failures occurred in the process system.

Table G-1 describes the limited information identified regarding the operations of the S-50 plant.

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Fox, M. C. 1945b. Memo to Roberts, C. W. re: S-50 plant, March 21, 1945.

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S-50 diary, February - May, 1945.

Table G-1
Limited Information About the Operating History of the S-50 Plant

Date	Reference	Reported Release (lbs. UF_6)	Remarks
7/1/40	LMES 1995		Program Start
4/30/41	LMES 1995		First column run with UF_6, NRL, Washington, DC
6/30/41	LMES 1995		Work expanded and moved to NRL, Anacostia
7/31/42	LMES 1995		New larger pilot plant authorized, 14 columns of 36 feet length
11/15/42	LMES 1995		New plant complete
5/15/42	LMES 1995		New plant data complete
8/31/42	LMES 1995		Program review, 236 #'s UF_6 shipped to Met Labs
8/31/43	LMES 1995		Favorable Program Review
11/17/43	Abelson et al. 1958		Pilot Plant in Philadelphia Naval Base Authorized; 3 racks 1/7 of S-50
1/1/44	LMES 1995		Philadelphia Pilot Plant Construction Started
9/2/44	LMES 1995		Serious Accident in Philadelphia, many changes, detailed physicals and blood studies show no effect from occasional breathing UI
6/26/44	LMES 1995		Site visit and decision to build S-50
12/31/44	LMES 1995		Philadelphia plant ships 5000 #s UF_6 0.86% to Oak RIdge
	LMES 1995		
	LMES 1995		
	LMES 1995		
6/6/44	LMES 1995		Construction Started
9/15/44	LMES 1995		First Tubes available for conditioning
9/17/44	LMES 1995		Partial Operations started
10/22/44	CCC 1945		K-25 weekly:S-50 = 548 kw, 43,577 # steam/hr; max steam 560,000 #/hr
10/31/44	LMES 1995		First product withdrawal, substantial construction completion
11/30/44	LMES 1995		95 pounds UF_6 produced in November
12/31/44	LMES 1995		95 pounds UF_6 produced in December
1/10/45	Fox 1945b		S-50 criticized for blowing down SP-1 steam line for 7 hours for repairs without condensate return
2/1/45	S-50 1945		Start of Medical Diary Entries
2/1/45	S-50 1945	360	15 people injured major release
2/15/45	S-50 1945	NR	
2/17/45	S-50 1945	NR	
2/19/45	S-50 1945		19 of 21 racks operating; #21 being reconditioned; steam leak shut down 2 racks; no serious leaks
2/21/45	S-50 1945	NR	
2/22/45	S-50 1945		15 racks in operation
2/23/45	S-50 1945		16 racks in operation
2/24/45	S-50 1945	NR	
2/26/45	S-50 1945		Small break TR#10; 18 exposures 3 sent to C&CCC
2/27/45	S-50 1945		Small break Rack #9 injury
2/27/45	S-50 1945		tour; heavy emanation from conditioning shop, rec. ventilation
3/1/45	S-50 1945		no serious incidents
3/2/45	S-50 1945		no serious incidents
3/3/45	S-50 1945	360	2/27/45 rec for ventilation now immediate installation
3/5/45	S-50 1945		major release last night;only four men first degree; depleted in TR#4 tank to tank transfer
3/7/45	S-50 1945		no major incidents in last 24 hours
3/8/45	S-50 1945		no major incidents last 24 hours
3/12/45	S-50 1945		blank

Table G-1
Limited Information About the Operating History of the S-50 Plant

3/14/45	S-50 1945		21 racks in operation since 3/13/45 a few small breaks; minor injuries
3/17/45	S-50 1945		21 racks in operation; one 24 hour period had no releases
3/19/45	S-50 1945		still having several small incidents w/o serious injuries every 24 hours; urine at 0.15 mg/l
3/21/45	S-50 1945		20 Racks in operation with only occasional small breaks of 157 men (10%of workforce) 88 had abnormal readings accd to Dr. Foul
3/21/45	S-50 1945		S-50 nearly forced into outage due to chronic loss of 60000 pounds per hour condensate to power house
3/22/45	S-50 1945		power house accident; shutdown from 0300-2400
3/26/45	S-50 1945		60 hour shutdown; @1500 13 racks in operation;25 people made sick in cafeteria - 10 hospitalized
3/27/45	S-50 1945		one exposure incident
3/28/45	S-50 1945		19 Racks in operation
3/30/45	S-50 1945		back to 19 racks; still several small breaks daily; occasional high urine excretion; building slit lamp room for eye exams
4/3/45	S-50 1945		limited steam supply restrictions on ops ended; trying to get urine samples at home (to avoid sample contamination?)
4/9/45	S-50 1945	400	21 Racks working; less problems with steam; warm weather a problem for protective clothing practices
4/20/45	S-50 1945		only minor breaks in last few days; 2/1/45 injury (hosp for 6 wks) re-hospitalized
4/21/45	S-50 1945		occasional minor break; 13 people sent to C&CCC dispensary; 4 kept; other 9 asked to return 4/23
4/30/45	S-50 1945	25	First reported loss from Material Shop
5/5/45	LMES 1995	9	bad connection on S.C. 1
5/11/45	S-50 1945		demo on chem warfare mask
5/13/45	S-50 1945		no more than 2/3 racks in operations due to steam supply;
5/13/45	S-50 1945		occasional small breaks; retook urine while in street clothes big reduction
5/15/45	LMES 1995	1	T.R.# 11
5/15/45	S-50 1945		operations on partial shutdown for period; 10 men used for medical study
5/19/45	LMES 1995		TR#8 Depleted material leaked badly
5/19/45	LMES 1995	5	TR #3 had break between 1000 and 1400
6/1/45	Dwyer 1945		production rate for May was 125 grams per column per day
6/2/45	S-50 1945		" operations on partial shutdown for period; 10 men used for medical study
6/30/45	S-50 1945		aux boiler for racks #1 to #7 planned
6/30/45	LMES 1995		12730 pounds UF_6 produced in June
7/1/45	Abelson et al. 1958		Oil FIred Steam Plant 400,000 lbs/hr at 450 psi completed
7/11/45	S-50 1945		temp shutdown 7/1/45 weekend; new boiler is being completed;
	S-50 1945		RIF planned 1100-1200 to 600-700
	S-50 1945		only a few high urines since improved technique
7/25/45	S-50 1945		urinanalyses ordered after high conditioning shop air samples
	S-50 1945		hoods and blowers had been installed but no motor
	S-50 1945		new boiler nearing completion
7/31/45	S-50 1945		motor installed; an attempt will be made to correlate air and urine
8/11/45	S-50 1945		operations resumed; hazard from loss of material while cleaning fixed
	S-50 1945		air samples OK but some urines high
8/11/45	S-50 1945		End of Medical Diary Entries
9/4/45	LMES 1995		Normal Operation Terminated
9/9/45	LMES 1995		S-50 shut down
10/1/47	LMES 1995		Development of water sampling for K-25 site, includes statement about S-50 losses from leaks to air thence to ground with leaks o
12/12/47	LMES 1995		Site drawings show F-01 Building removed
	Total UF_6 (pounds) =	1160	

APPENDIX H

X-10 ATMOSPHERIC SOURCE TERM

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BASIS OF X-10 AIRBORNE URANIUM RELEASE ESTIMATES FOR TASK 6 SCREENING

For Task 6 screening of airborne releases from X-10, uranium release estimates from the Dose Reconstruction Feasibility Study were used. In the Dose Reconstruction Feasibility Study (ChemRisk 1993), historical uranium releases to the atmosphere were estimated for:

1) early separation of plutonium in the Chemical Processing Pilot Plant [1944-1945],

2) radioactive barium/lanthanum separation operations [1944-1956],

3) processing of freshly-irradiated thorium using the Thorex process [1956-1957], and

4) ruptures of Clinton Pile (Graphite Reactor) fuel slugs [1944-1948].

Uranium Releases from Early Plutonium Production

The amount of uranium available in fuel slugs that were processed for this operation was estimated to be 0.3 tons per day over 365 days. This natural uranium was assumed to be 0.71% ^{235}U and 99.28% ^{238}U by weight. A release fraction of 0.1% was applied to the available uranium inventory.

Uranium Releases from Barium/Lanthanum Processing

Air releases from RaLa processing were estimated based on production records and estimated radionuclide inventories of fuel slugs. Screening-level estimates of releases were developed for 1947, the year of peak Oak Ridge slug processing, and for 1952, the year of peak processing of Hanford slugs at Oak Ridge. Uranium content of Oak Ridge slugs was estimated based on 2.6 pounds of natural uranium per slug, with an isotopic composition of 99.276% ^{238}U and 0.71% ^{235}U. Hanford slugs during 1952 were assumed to have masses of 1,800 grams. Fractions of available radionuclides released during processing were estimated to be 0.1% for radionuclides in particulate form (including uranium). The release fraction for particulates was based on measurements from RaLa processing at the Idaho National Engineering Laboratory in 1957.

Uranium Releases from Thorex Processing

Uranium-233 is an activation product of thorium. Quantities of ^{233}U that were contained in the dissolved, irradiated thorium metal were estimated by multiplying the kilograms of uranium reported to have been dissolved in each batch by 9.48, the number of curies of ^{233}U per kilogram of ^{233}U. A release fraction of 0.1% was applied to the available uranium inventory.

Uranium Releases from Clinton Pile/Graphite Reactor Slug Ruptures

All slug rupture events were assumed to involve single slugs, except for the events of November 30, 1947 and August 25, 1948, which involved 13 and 5 slugs, respectively. Quantities of uranium involved were estimated by multiplying the documented number of slugs ruptured by the assumed slug mass of 2.6 pounds of natural uranium metal. A 0.71% ^{235}U and 99.276% ^{238}U content was assumed. Ten percent of the uranium present in each ruptured slug was assumed to have been released to the atmosphere after the uranium oxidized.

In cases where the Feasibility Study provided estimates for peak years of processing, these peak estimates were replicated through all years of duration for each operation of interest:

- Releases from early Pu separation apply to 1944 and early 1945.
- Releases from RaLa processing apply from 1944 through 1956.
- Releases of ^{233}U were not addressed in the Task 6 evaluation, as it was not a significant component of most of the uranium handled on the Oak Ridge Reservation.
- Releases from Clinton Pile/Graphite Reactor slug ruptures applied from 1944 through 1948.

APPENDIX I

QUALITY OF SCARBORO AIR MONITORING DATA

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APPENDIX I: QUALITY OF SCARBORO AIR MONITORING DATA

The Task 6 project team conducted reviews of the quality of the air sampling practices and methods used to evaluate measurement data and report uranium concentrations in air. The purpose of these reviews was to determine if the methods used by ORNL for estimating uranium air concentrations measured at Scarboro meet minimum acceptable industry standards and yielded results of sufficient quality to be used in the Task 6 χ/Q evaluation.

The project team's review of the Scarboro monitor and sampling results involved review of relevant documents and interviews with active and retired ORNL workers. In addition, the project team submitted a list of questions to ORNL staff regarding historical air sampling practices and techniques used to estimate Scarboro uranium air concentrations. Five steps used by the project team in evaluating the quality of Scarboro air monitoring data were:

1) review of documents that describe methods and procedures for air sample collection and measurement of radioactivity collected on filter samples,

2) a project team visit to the ORNL Analytical Services Laboratory to observed laboratory procedures and handling of air samples by lab personnel,

3) interviews with ORNL Analytical and Health Physics field personnel,

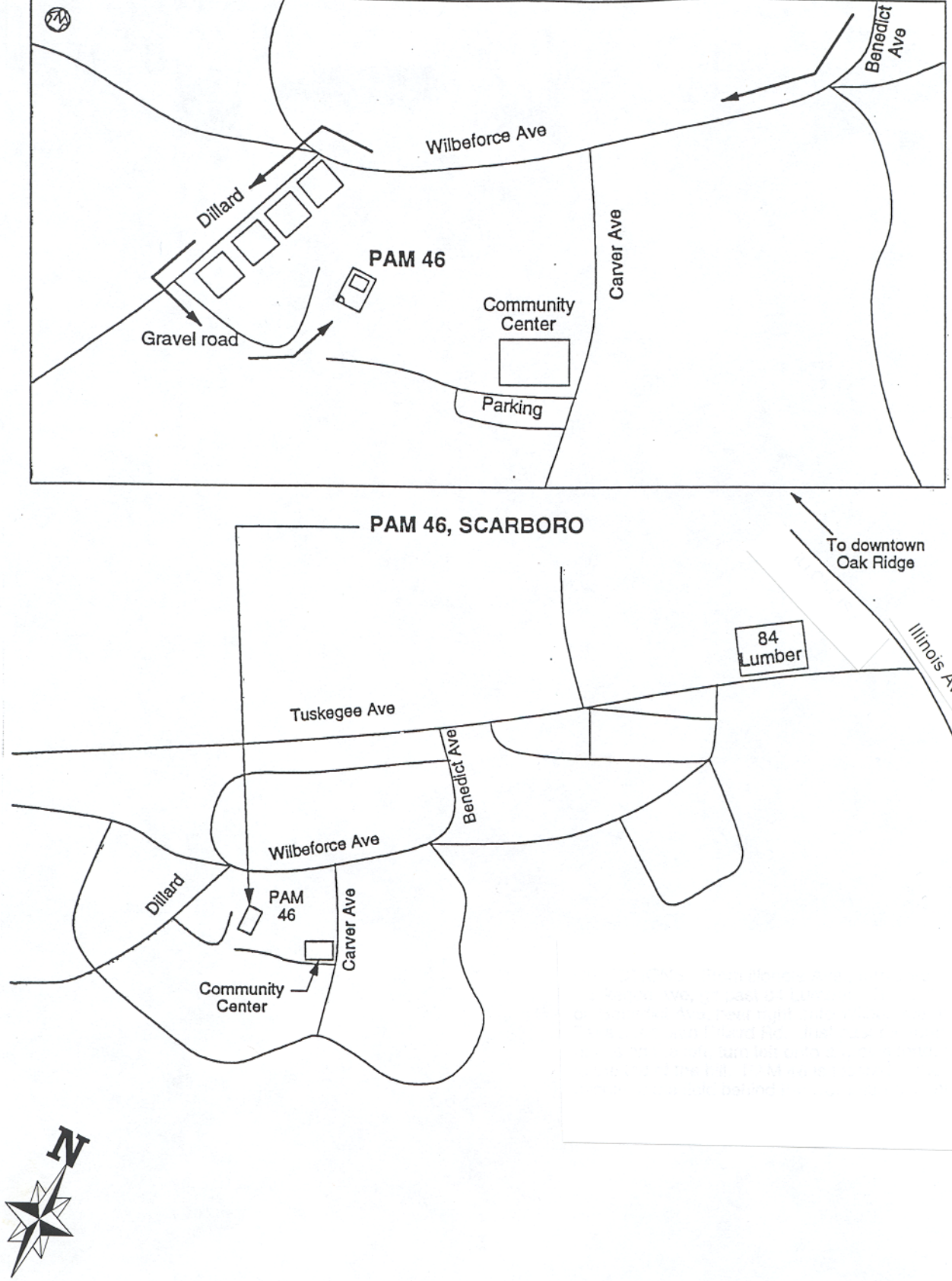
4) interviews with ORNL Environmental Monitoring staff regarding data collection and reporting of uranium air concentrations based on results of Scarboro samples, and

5) site visit by project team members to the Scarboro station.

A continuous air monitoring station was installed in the Scarboro community during the 3rd quarter of 1986, and was operational and generating data by the 4th quarter. This air monitoring station (Station #46) was placed in the Scarboro community just west of the Mount Zion Church on Tuskegee Drive, approximately 140 meters west of the Scarboro Community Center. Since installation, the monitoring station has provided quarterly and annual measurements of ^{234}U, ^{235}U and ^{238}U in air, and has been operated and maintained by ORNL. The station is operated as part of the DOE ORR air monitoring network, and was initially designated as Station A46. Later reports referred to this sampling as Station 46. Figure I-1 shows the general location of the station in relation to the Scarboro community. Figure I-2 shows the general layout of the station, including locations of the various monitoring and control devices.

A typical alpha spectroscopy report generated by ORNL is provided in Figure I-3. Typical alpha spectra used by ORNL technicians to identify and quantify isotope concentrations from air samples are shown in Figure I-4. These are some of the types of data the project team reviewed to assess the quality of measurement data used by ORNL to estimate airborne uranium concentrations in Scarboro. Figure I-5 is a calibration alpha spectrum which, when compared to the spectra generated by the air sample, can be used to identify the radioisotopes being measured.

Based on this review, the project team concluded that the Scarboro monitoring station provides an adequate assessment of average airborne uranium that might be encountered in the Scarboro community and is suitable for the Task 6 χ/Q evaluation. Additional use of the Scarboro monitoring data may be useful in future study of ORR uranium.



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A Service of McLaren/Hart

FIGURE I-1
LOCATION OF PERIMETER AIR MONITOR (PAM) 46, SCARBORO
(Courtesy of ORNL)

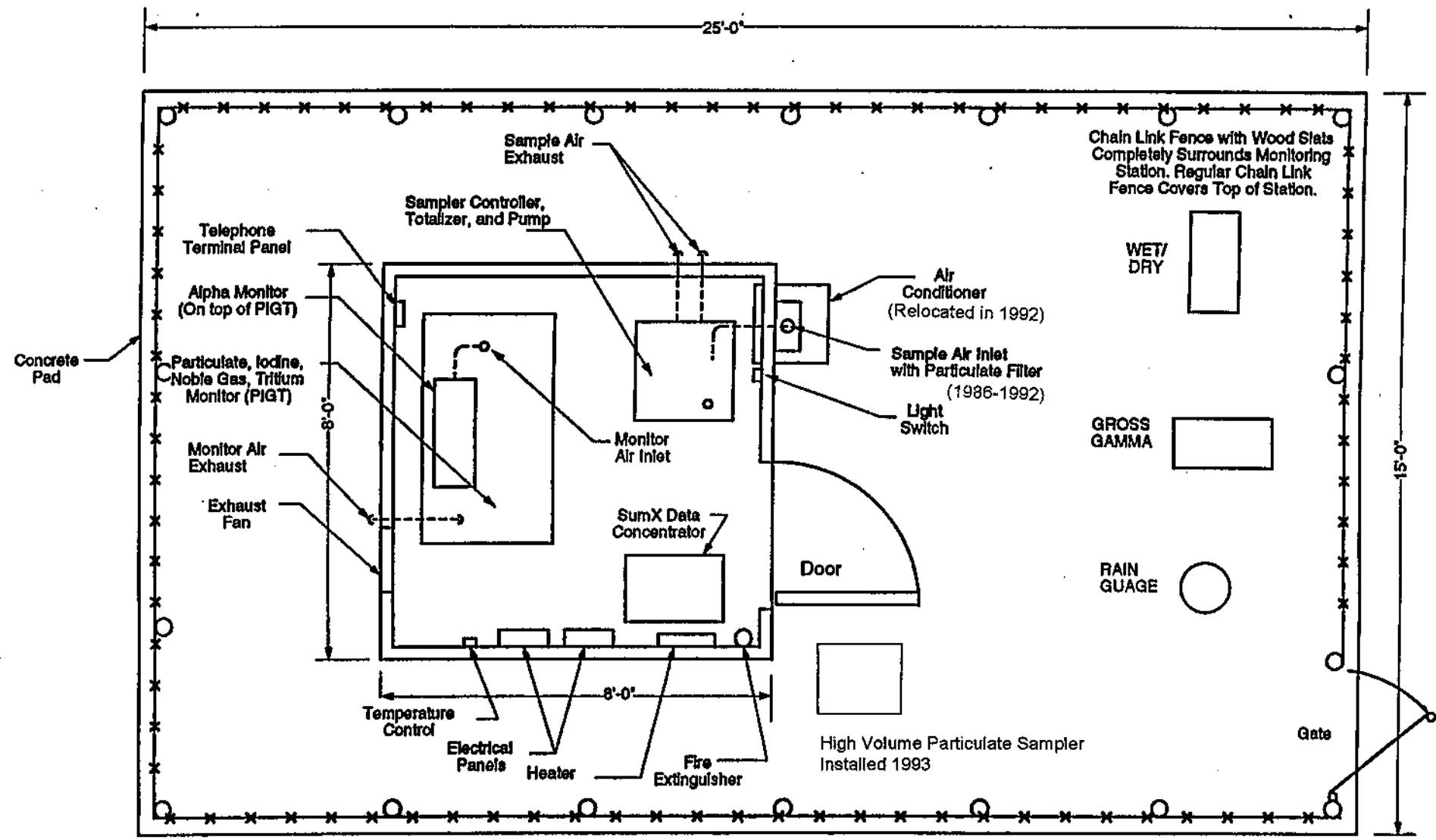

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FIGURE I-2
SITE PLAN FOR PERIMETER AIR MONITOR (PAM) 46, SCARBORO
(Courtesy of ORNL)

MMES Analytical Services Organization, Y-12 Site
Environmental Radiometry Facility

ALPHA SPECTROSCOPY REPORT
21-NOV-1996 11:19:36

Spectral File: ND_SC_ARCHIVE_S:S_X101120$X961009054_UU.CNF

SAMPLE TITLE: SX961009054UU
SAMPLE DATE: 9-OCT-1996 00:00:00.
ELAPSED LIVE TIME: 59967.
AVERAGE EFFICIENCY: 18.54%
TRACER ID: U-X10
LAMBDA VALUE: 100.
CUSTODY/BATCH ID: X101120
Acquisition Date: 20-NOV-1996 17:10:4

SAMPLE ID: X961009054
SAMPLE QUANT: 0.250000 filter
DETECTOR #: 019
YIELD: 87.98%
TRACER DPM AT SAMPLE DATE: 4.926
CONFIDENCE LEVEL: 4.65
LLD CONSTANT: 2.71

NUCLIDE ACTIVITY SUMMARY

NUCLIDE	ENERGY	NET AREA	BKG	%ABN	ACTIVITY Bq /filter	ERROR 2-SIGMA	MDC Bq /filter
U232	5306.	802.222	2.778	100.00	3.284E-01	2.690E-02	4.277E-03
U-234	4762.	88.000	0.000	100.00	3.598E-02	8.350E-03	1.108E-03
U-235	4386.	1.306	0.694	80.20	6.656E-04	1.608E-03	3.357E-03
U-236	4481.	1.917	2.083	100.00	7.837E-04	1.911E-03	3.852E-03
U-238	4185.	67.222	2.778	99.80	2.754E-02	7.394E-03	4.285E-03

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FIGURE I-3
TYPICAL APLHA SPECTROSCOPY REPORT FOR SCARBORO AIR SAMPLES
(Courtesy of ORNL)

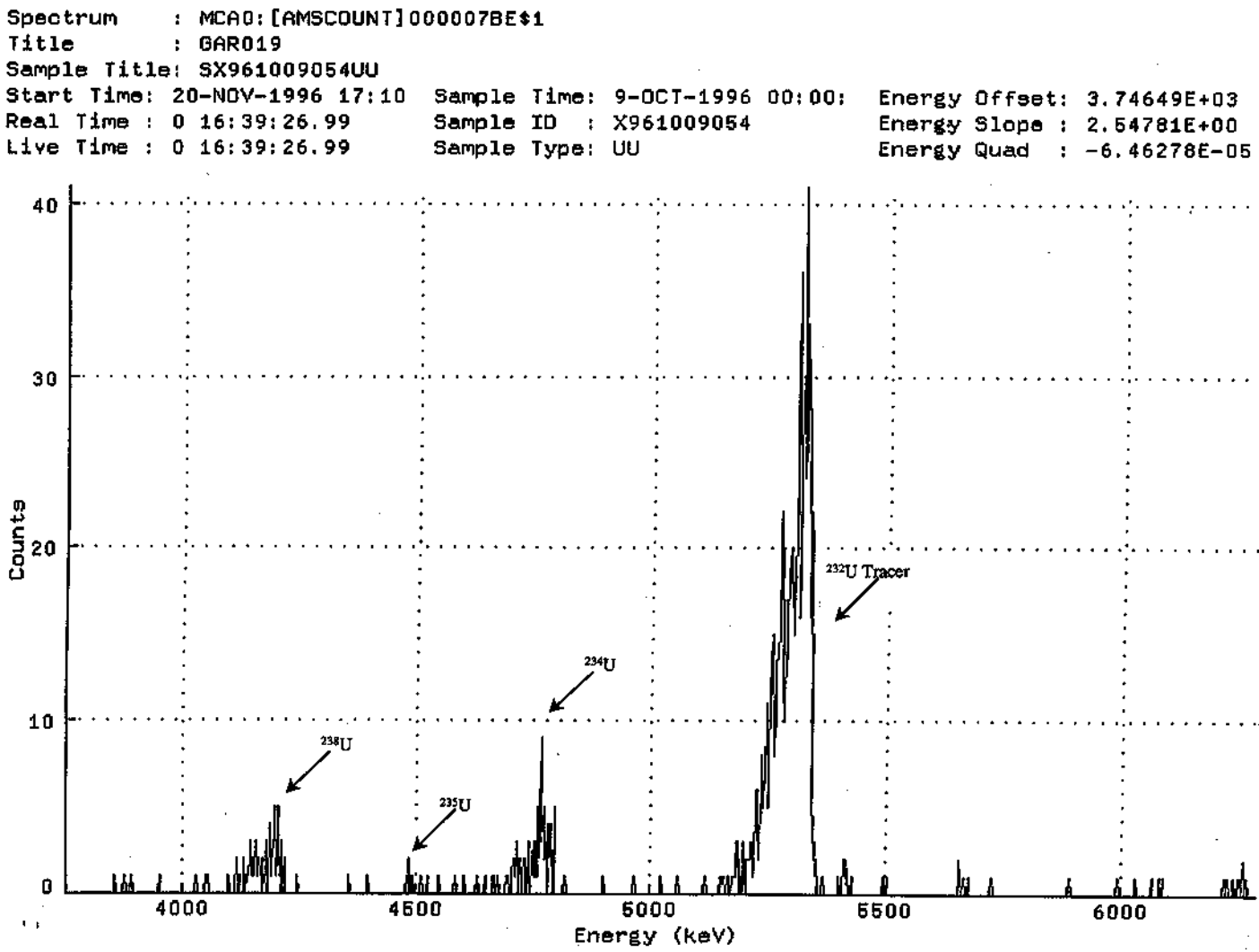

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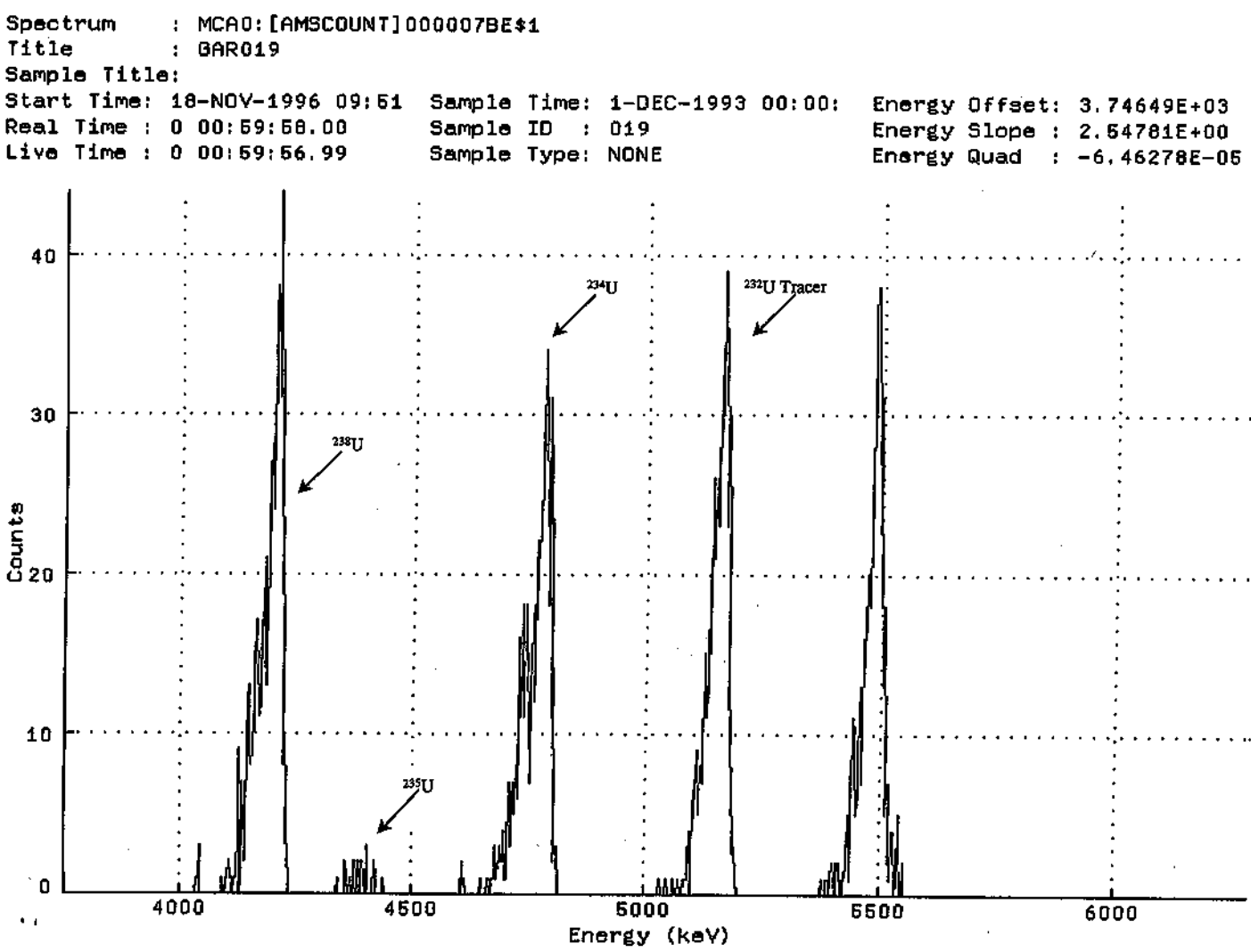
FIGURE I-4
TYPICAL ALPHA SPECTROGRAPH FOR URANIUM AIR SAMPLES
(Courtesy of ORNL)



ChemRisk
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FIGURE I-5
TYPICAL ALPHA SPECTROGRAPH USED FOR URANIUM CALIBRATION
(Courtesy of ORNL)

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APPENDIX J

EXPOSURE PATHWAY EQUATIONS USED FOR THE TASK 6 SCREENING ASSESSMENT

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APPENDIX J: EXPOSURE PATHWAY EQUATIONS USED FOR THE TASK 6 SCREENING ASSESSMENT

This appendix presents the exposure pathway equations used in the Task 6 screening assessment. These equations are consistent with those that have been developed by various regulatory agencies for evaluating exposures to chemicals and radionuclides (USEPA 1979; NCRP 1996; USEPA 1989). Two sets of equations are presented for each exposure pathway: radionuclide intakes are expressed in terms of picocurie per day (pCi d^{-1}) and chemical intakes are expressed as milligrams per day (mg d^{-1}). The pathways of exposure for the three media of concern (air, surface water, and soil) are defined and discussed in Section 4 of the report. Pathways represent mechanisms and routes by which uranium can come in contact with the individual. Some of these pathways are direct, such as the inhalation of contaminated air, whilst others require significantly complex modeling. Complex models are used to assess the intake through multiple intermediate media, such as the intake of beef from cattle grazing on contaminated pasture from the deposition of airborne materials. The equations used to quantify exposure from these pathways are presented below.

REFERENCES FOR APPENDIX J

NCRP 1996. National Council on Radiation Protection and Measurements (NCRP). Screening Models for Releases of Radionuclides to Air, Surface Water and Ground. NCRP Report No. 123

USEPA 1979. U.S. Environmental Protection Agency. AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides. Prepared by the Oak Ridge National Laboratory for the Office of Radiation Programs, Washington, D.C. EPA 520/1-79-009.

USEPA 1989. U.S. Environmental Protection Agency. Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A)—Interim Final. Office of Emergency and Remedial Response, Washington, D.C. EPA/540/1-89/002. December 1989.

AIR 6 HUMANS (INHALATION)

$I_{air} = C_{air} U_{air}$ radionuclides

$I_{air} = C_{air} U_{air}$ chemicals

where:

I_{air} = Daily intake of contaminant due to inhalation,
pCi d^{-1} (radionuclides)
mg d^{-1} (chemicals);

C_{air} = Average concentration of contaminant in air,
pCi m^{-3} (radionuclides)
mg m^{-3} (chemicals);

U_{air} = Average volume of air inhaled per day, (m^3 d^{-1});

f_t = Fraction of time that a person is exposed, dimensionless;

f_s = Indoor/outdoor shielding factor, dimensionless;

B_{inh} = Bioavailability (inhalation), dimensionless.

AIR 6 HUMANS (IMMERSION) - RADIONUCLIDES ONLY

$$I_{imm}\ (air) = C_{air}\ f_t\ f_s$$

where:

I_{imm}(air) = Exposure from immersion in contaminated air, pCi m^{-3};

C_{air} = Average concentration of contaminant in air, pCi m^{-3};

f_t = Fraction of time exposed to contaminated air, dimensionless;

f_s = Indoor/outdoor shielding factor, dimensionless;

AIR 6 LIVESTOCK/GAME (BEEF) 6 HUMANS (INGESTION)

Equation #1

$$C_{beef(air)} = C_{air}\ Q_{air(b)}\ F_f$$

where:

$C_{beef(air)}$	=	Equilibrium concentration of contaminant in beef due to inhalation, mg kg^{-1} or pCi kg^{-1};
C_{air}	=	Average concentration of contaminant in air, mg m^{-3} or pCi m^{-3};
$Q_{air(b)}$	=	Daily inhalation rate of beef cattle, m^3 d^{-1}; and
F_f	=	Biotransfer factor from cattle intake to meat concentration (mg kg^{-1})/(mg d^{-1}) or (pCi kg^{-1})/(pCi d^{-1}).

Equation #2

$$I_{beef(air)} = C_{beef(air)}\ U_{beef}\ f_{cb}\ B_{oral} \qquad \text{chemical}$$

$$I_{beef(air)} = C_{beef(air)}\ U_{beef}\ f_{cm} \qquad \text{radionuclide}$$

where:

$I_{beef(air)}$	=	Daily intake of contaminant due to beef ingestion (air pathway), mg d^{-1} or pCi d^{-1};
$C_{beef(air)}$	=	Equilibrium concentration of contaminant in beef due to inhalation, mg kg^{-1} or pCi kg^{-1};
U_{beef}	=	Average daily consumption of beef, kg d^{-1};
f_{cb}	=	Fraction of beef consumed that is contaminated, dimensionless;
B_{oral}	=	Bioavailability; ingestion.

AIR 6 DAIRY CATTLE (MILK) 6 HUMANS (INGESTION)

Equation #1

$$C_{milk(air)} = C_{air} \; Q_{air(d)} \; F_m$$

where:

$C_{milk(air)}$ = Equilibrium concentration of contaminant in milk due to inhalation, mg L^{-1} or pCi L^{-1};

C_{air} = Average concentration of contaminant in air, mg m^{-3} or pCi m^{-3};

$Q_{air(d)}$ = Daily inhalation rate of dairy cattle, m^3 d^{-1}; and

F_m = Biotransfer factor from cattle intake to milk concentration, (mg L^{-1})/(mg d^{-1}) or (pCi L^{-1})/(pCi d^{-1}).

Equation #2

$$I_{milk(air)} = C_{milk(air)} \; U_{milk} \; f_{cm} \; B_{oral} \qquad \text{chemical}$$

$$I_{milk(air)} = C_{milk(air)} \; U_{milk} \; f_{cm} \qquad \text{radionuclide}$$

where:

$I_{milk(air)}$ = Daily intake of contaminant due to milk ingestion (air pathway), mg d^{-1} (chemical) or pCi d^{-1} (radionuclide);

$C_{milk(air)}$ = Equilibrium concentration of contaminant in milk due to inhalation, mg L^{-1} or pCi L^{-1};

U_{milk} = Average daily consumption of milk, L d^{-1};

f_{cm} = Fraction of milk consumed that is contaminated, dimensionless,

B_{oral} = Bioavailability; ingestion.

AIR (PARTICULATES) 6 VEGETABLES 6 HUMANS (INGESTION)

Equation #1

$$C_{veg(air)} = C_{air} V_{D(veg)} \left(\frac{1 - e^{-k_w T_g}}{k_w}\right) f_w$$

where:

$C_{veg(air)}$ = Equilibrium concentration of contaminant on washed leafy vegetables (wet weight), mg kg^{-1} or pCi kg^{-1};

C_{air} = Average concentration of contaminant in air, mg m^{-3} or pCi m^{-3};

$V_{D(veg)}$ = Wet/Dry deposition velocity per unit mass of vegetation [(m d^{-1})/(kg m^{-2})];

k_w = Weathering rate constant, d^{-1};

T_g = Growth period or exposure period, d;

f_w = Fraction of contaminant remaining after washing, dimensionless.

Equation #2

$$I_{veg(air)} = C_{veg} U_{veg} f_{cv} B_{oral} \quad \text{chemical}$$

$$I_{veg(air)} = C_{veg} U_{veg} f_{cv} \quad \text{radionuclide}$$

where:

$I_{veg(air)}$ = Daily intake of contaminant due to leafy vegetables ingestion, mg d^{-1} or pCi d^{-1};

$C_{veg(air)}$ = Equilibrium concentration of contaminant on washed leafy vegetables (wet weight), mg kg^{-1} or pCi kg^{-1};

U_{veg} = Average daily consumption of vegetables (wet weight), kg d^{-1};

f_{cv} = Fraction of vegetables consumed that is contaminated, dimensionless.

B_{oral} = Bioavailability; ingestion.

AIR (PARTICULATES) 6 PASTURE 6 LIVESTOCK/GAME (BEEF) 6 HUMANS (INGESTION)

Equation #1

$$C_{past(air)} = C_{air} V_{D(past)} \left(\frac{1 - e^{-k_w T_g}}{k_w} \right)$$

where:

$C_{past(air)}$	=	Equilibrium concentration of contaminant on pasture (dry weight), mg kg^{-1} or pCi kg^{-1};
C_{air}	=	Average concentration of contaminant in air, mg m^{-3} or pCi m^{-3};
$V_{D(past)}$	=	Wet/Dry deposition velocity per unit mass of vegetation [(m d^{-1})/(kg m^{-2})];
k_w	=	Weathering rate constant, d^{-1}; and
T_g	=	Growth period or exposure period, d.

Equation #2

$$C_{beef(past)} = C_{past(air)} Q_{past(b)} F_f f_{pb}$$

where:

$C_{beef(past)}$	=	Equilibrium concentration of contaminant in beef (air pathway), mg kg^{-1} or pCi kg^{-1};
$C_{past(air)}$	=	Equilibrium concentration of contaminant on pasture (dry weight) mg kg^{-1} or pCi kg^{-1};
$Q_{past(b)}$	=	Daily ingestion of pasture (dry weight) by beef cattle, kg d^{-1};
F_f	=	Biotransfer factor from cattle intake to meat concentration, (mg kg^{-1})/(mg d^{-1}) or (pCi kg^{-1})/(pCi d^{-1}); and
f_{pb}	=	Fraction of feed ingested by beef cattle that is pasture, dimensionless.

Equation #3

$$I_{beef(past)} = C_{beef(past)}\ U_{beef}\ f_{cb}\ B_{oral} \qquad \text{chemical}$$

$$I_{beef(past)} = C_{beef(past)}\ U_{beef}\ f_{cb} \qquad \text{radionuclide}$$

where:

$I_{beef(past)}$	=	Daily intake of contaminant due to beef ingestion (pasture), mg d^{-1} or pCi d^{-1};
$C_{beef(past)}$	=	Equilibrium concentration of contaminant in beef due to pasture, mg kg^{-1} or pCi kg^{-1};
U_{beef}	=	Average daily consumption of beef, kg d^{-1};
f_{cb}	=	Fraction of beef consumed that is contaminated, dimensionless.
B_{oral}	=	Bioavailability; ingestion.

AIR (PARTICULATES) 6 PASTURE 6 DAIRY CATTLE (MILK) 6 HUMANS (INGESTION)

Equation #1

$$C_{past(air)} = C_{air}\ V_{D(past)} \left(\frac{1 - e^{-k_w T_g}}{k_w} \right)$$

where:

$C_{past(air)}$	=	Equilibrium concentration of contaminant on pasture (dry weight), mg kg^{-1} or pCi kg^{-1};
C_{air}	=	Average concentration of contaminant in air, mg m^{-3} or pCi m^{-3};
$V_{D(past)}$	=	Wet/Dry deposition velocity per unit mass of vegetation [(m d^{-1})/(kg m^{-2})];

k_w = Weathering rate constant, d^{-1}; and

T_g = Growth period or exposure period, d.

Equation #2

$$C_{milk(past)} = C_{past(air)} \, Q_{past(d)} \, F_m \, f_{pd}$$

where:

$C_{milk(past)}$ = Equilibrium concentration of contaminant in milk (air pathway), mg L^{-1} or pCi L^{-1};

$C_{past(air)}$ = Equilibrium concentration of contaminant on pasture (dry weight), mg kg^{-1} or pCi kg^{-1};

$Q_{past(d)}$ = Daily ingestion of pasture (dry weight) by dairy cattle, kg d^{-1};

F_m = Biotransfer factor from cattle intake to milk concentration, (mg L^{-1})/(mg d^{-1}) or (pCi L^{-1})/(pCi d^{-1});

f_{pd} = Fraction of feed ingested by dairy cattle that is pasture, dimensionless.

Equation #3

$$I_{milk(past)} = C_{milk(past)} U_{milk} \, f_{cm} \qquad \text{radionuclide}$$

$$I_{milk(past)} = C_{milk(past)} U_{milk} \, f_{cm} \, B_{oral} \qquad \text{chemical}$$

where:

$I_{milk(past)}$ = Daily intake of contaminant due to milk ingestion (pasture), mg d^{-1} or pCi d^{-1};

$C_{milk(past)}$ = Equilibrium concentration of contaminant in milk due to pasture, mg L^{-1} or pCi L^{-1};

U_{milk} = Average daily consumption of milk, L d^{-1};

f_{cm} = Fraction of milk consumed that is contaminated, dimensionless

B_{oral} = Bioavailability; ingestion.

WATER 6 HUMANS
(INCIDENTAL INGESTION FROM SURFACE WATER RECREATION)

$$I_{water}(incidental) = C_{water}\ U_{water\ (inc)}\ ET\&A\ B_{oral}$$ chemical

$$I_{water}(incidental) = C_{water}\ U_{water\ (inc)}\ ET\&A$$ radionuclide

where:

I_{water}(incidental) = Daily intake of contaminant due to incidental water consumption during surface water recreational activities, mg d^{-1} or pCi d^{-1};

C_{water} = Average concentration of contaminant in water, mg L^{-1} or pCi L^{-1} (EFPC or Clinch River);

$U_{water\ (inc)}$ = Average consumption of contaminated surface water during recreational activities, L hr^{-1};

ET-A = Exposure time-incidental ingestion of surface water (hr d^{-1})

B_{oral} = Bioavailability; ingestion.

WATER 6 LIVESTOCK/GAME (BEEF) 6 HUMANS (INGESTION)

Equation #1

$$C_{beef(water)} = C_{water}\ Q_{water(b)}\ F_f\ f_{cw}$$

where:

$C_{beef(water)}$ = Equilibrium concentration of contaminant in beef due to drinking contaminated water, mg kg^{-1} or pCi kg^{-1};

C_{water} = Average concentration of contaminant in water, mg L^{-1} or pCi L^{-1};

$Q_{water(b)}$ = Daily intake of water by beef cattle, L d^{-1};

F_f = Biotransfer factor from cattle intake to meat concentration, (mg kg^{-1})/(mg d^{-1}) or (pCi kg^{-1})/(pCi d^{-1});

f_{cw} = Fraction of water obtained from a contaminated source, dimensionless.

Equation #2

$$I_{beef(water)} = C_{beef(water)}\ U_{beef}\ f_{cb} \qquad \text{radionuclide}$$

$$I_{beef(water)} = C_{beef(water)} U_{beef}\ f_{cb}\ B_{oral} \qquad \text{chemical}$$

where:

$I_{beef(water)}$ = Daily intake of contaminant due to beef ingestion (water pathway); mg d^{-1} or pCi d^{-1};

$C_{beef(water)}$ = Equilibrium concentration of contaminant in beef due to water, mg kg^{-1} or pCi kg^{-1};

U_{beef} = Average daily consumption of beef, kg d^{-1};

f_{cb} = Fraction of beef consumed that is contaminated, dimensionless.

B_{oral} = Bioavailability; ingestion.

WATER 6 DAIRY CATTLE (MILK) 6 HUMANS (INGESTION)

Equation #1

$$C_{milk(water)} = C_{water}\ Q_{water(d)}\ F_m\ f_{cw}$$

where:

$C_{milk(water)}$	=	Equilibrium concentration of contaminant in milk due to drinking contaminated water, mg L^{-1} or pCi L^{-1};
C_{water}	=	Average concentration of contaminant in water, mg L^{-1} or pCi L^{-1};
$Q_{water(d)}$	=	Daily intake of water by dairy cattle, L d^{-1};
F_m	=	Biotransfer factor from cattle intake to milk concentration, (mg L^{-1})/(mg d^{-1}) or (pCi L^{-1})/(pCi d^{-1});
f_{cw}	=	Fraction of water obtained from a contaminated source, dimensionless.

Equation #2

$$I_{milk(water)} = C_{milk(water)} U_{milk}\ f_{cm}\ B_{oral} \qquad \text{chemical}$$

$$I_{milk(water)} = C_{milk(water)}\ U_{milk}\ f_{cm} \qquad \text{radionuclide}$$

where:

$I_{milk(water)}$	=	Daily intake of contaminant due to milk ingestion (water pathway), mg d^{-1} or pCi d^{-1};
$C_{milk(water)}$	=	Equilibrium concentration of contaminant in milk due to water, mg L^{-1} or pCi L^{-1};
U_{milk}	=	Average daily consumption of milk, L d^{-1};
f_{cm}	=	fraction of milk consumed that is contaminated.
B_{oral}	=	Bioavailability; ingestion.

WATER 6 FISH 6 HUMANS (INGESTION)

Equation #1

$$C_{fish} = C_{water} \, BCF$$

where:

C_{fish} = Equilibrium concentration of contaminant in fish, mg kg^{-1} or pCi kg^{-1};

C_{water} = Average concentration of contaminant in water, mg L^{-1} or pCi L^{-1}; and

BCF = Bioconcentration factor, (mg kg^{-1})/(mg L^{-1}) or (pCi kg^{-1})/(pCi L^{-1}).

Equation #2

$$I_{fish} = C_{fish} \, U_{fish} \, f_{cf} \, B_{oral} \qquad \text{chemical}$$

where:

$$I_{fish} = C_{fish} \, U_{fish} \, f_{cf} \qquad \text{radionuclide}$$

I_{fish} = Daily intake of contaminant per unit body weight due to fish ingestion, mg d^{-1} or pCi d^{-1};

C_{fish} = Equilibrium concentration of contaminant in fish, mg kg^{-1} or pCi kg^{-1};

U_{fish} = Average daily consumption of fish, kg d^{-1}

f_{cf} = Fraction of fish consumed that is contaminated, dimensionless.

B_{oral} = Bioavailability; ingestion.

WATER 6 HUMANS (RECREATIONAL IMMERSION) - RADIONUCLIDES ONLY

$$I_{(water)imm} \text{ ' } C_{water}\ ET\&A\ Cf_1\ Cf_2$$

where:

$I_{(water)imm}$	=	Exposure due to water immersion, pCi m^{-3};
C_{water}	=	Average concentration of contaminant in water, pCi L^{-1};
ET-A	=	Exposure time, hr d^{-1};
Cf_1	=	Conversion factor, L m^{-3};
Cf_2	=	Conversion factor, d hr^{-1}.

SOIL 6 AIR 6 HUMANS (INHALATION)

Equation #1

$$C_{(air)resus} \text{ ' } A\ M\ F\ Cf_1$$

where:

$C_{(air)resus}$	=	Average concentration of contaminant in air due to resuspension, mg m^{-3} or pCi m^{-3};
A	=	Equilibrium concentration of contaminant on surface soil, mg kg^{-1} or pCi kg^{-1};
M	=	Mass loading of particles in ambient air, mg m^{-3};
F	=	Enhancement factor, dimensionless; and
Cf_1	=	Conversion factor, kg mg^{-1}.

Equation #2

$$Intake_{(air)resus} = C_{(air)resus}\ U_{air}\ f_t\ f_s\ B_{inhal} \qquad \text{chemical}$$

$$Intake_{(air)resus} = C_{(air)resus}\ U_{air}\ f_t\ f_s \qquad \text{radionuclide}$$

where:

$\boldsymbol{Intake_{(air)resus}}$ = Daily intake of contaminant due to inhalation of resuspended particulates, mg d^{-1} or pCi d^{-1};

$\boldsymbol{C_{(air)resus}}$ = Average concentration of resuspended contaminant in air, mg m^{-3} or pCi m^{-3};

$\boldsymbol{U_{air}}$ = Average volume of air inhaled per day, m^3 d^{-1};

$\boldsymbol{f_t}$ = Fraction of time that a person is exposed, dimensionless;

$\boldsymbol{f_s}$ = Indoor/outdoor shielding factor, dimensionless; and

$\boldsymbol{B_{inhal}}$ = Bioavailability; inhalation.

SOIL 6 HUMANS (INGESTION)

$$I_{soil} = C_{soil(surf)}\ U_{soil}\ f_{sc}\ B_{oral} \qquad \text{chemical}$$

$$I_{soil} = C_{soil(surf)}\ U_{soil}\ f_{sc} \qquad \text{radionuclide}$$

where:

$\boldsymbol{I_{soil}}$ = Daily intake of contaminant per unit body weight due to soil ingestion, mg d^{-1} or pCi d^{-1};

$\boldsymbol{C_{soil(surf)}}$ = Equilibrium concentration of contaminant in soil, mg kg^{-1} or pCi kg^{-1};

$\boldsymbol{U_{soil}}$ = Average daily ingestion of soil, kg d^{-1};

$\boldsymbol{f_{sc}}$ = Fraction of soil ingested that is contaminated, dimensionless.

$\boldsymbol{B_{oral}}$ = Bioavailability; ingestion.

SOIL 6 LIVESTOCK/GAME (BEEF) 6 HUMANS (INGESTION)

Equation #1

$$C_{beef(soil)} = C_{soil(surf)}\ Q_{soil(b)}\ B_{meat}\ f_{csb}$$

where:

$C_{beef(soil)}$	=	Equilibrium concentration of contaminant in beef due to soil ingestion, mg kg^{-1} or pCi kg^{-1};
$C_{soil(surf)}$	=	Equilibrium concentration of contaminant in surface soil, mg kg^{-1} or pCi kg^{-1};
$Q_{soil(b)}$	=	Daily ingestion rate of soil by beef cattle, kg d^{-1};
B_{meat}	=	Biotransfer factor from cattle intake to meat concentration, (mg kg^{-1})/(mg d^{-1}) or (pCi kg^{-1})/(pCi d^{-1}); and
f_{csb}	=	Fraction of soil ingested by beef cattle that is contaminated, dimensionless.

Equation #2

$$I_{beef(soil)} = C_{beef(soil)}\ U_{beef}\ f_{cb} \qquad \text{radionuclide}$$

$$I_{beef(soil)} = C_{beef(soil)}\ U_{beef}\ f_{cb}\ B_{oral} \qquad \text{chemical}$$

here:

$I_{beef(soil)}$	=	Daily intake of contaminant due to beef ingestion, mg d^{-1} or pCi d^{-1}
$C_{beef(soil)}$	=	Equilibrium concentration of contaminant in beef due to soil ingestion, mg kg^{-1} or pCi kg^{-1};
U_{beef}	=	Average daily consumption of beef, kg d^{-1};
f_{cb}	=	Fraction of beef consumed that is contaminated, dimensionless.
B_{oral}	=	Bioavailability; ingestion.

SOIL 6 DAIRY CATTLE (MILK) 6 HUMANS (INGESTION)

Equation #1

$$C_{milk(soil)} = C_{soil(surf)}\ Q_{soil(d)}\ F_m\ f_{csd}$$

where:

$C_{milk(soil)}$	=	Equilibrium concentration of contaminant in milk due to soil ingestion, mg L^{-1} or pCi L^{-1};
$C_{soil(surf)}$	=	Equilibrium concentration of contaminant in surface soil, mg kg^{-1} or pCi kg^{-1};
$Q_{soil(d)}$	=	Daily ingestion rate of soil by dairy cattle, kg d^{-1};
F_m	=	Biotransfer factor from cattle intake to milk concentration, (mg L^{-1})/(mg d^{-1}) or (pCi L^{-1})/(pCi d^{-1}); and
f_{csd}	=	Fraction of soil ingested by dairy cattle that is contaminated, dimensionless.

Equation #2

$$I_{milk} = C_{milk(soil)}\ U_{milk}\ f_{cm}\ B_{oral} \qquad \text{chemical}$$

$$I_{milk} = C_{milk(soil)}\ U_{milk}\ f_{cm} \qquad \text{radionuclide}$$

where:

I_{milk}	=	Daily intake of contaminant per unit body weight due to milk ingestion, mg d^{-1} or pCi d^{-1};
$C_{milk(soil)}$	=	Equilibrium concentration of contaminant in milk due to soil ingestion, mg L^{-1} or pCi L^{-1};
U_{milk}	=	Average daily consumption of milk, L d^{-1};
f_{cm}	=	Fraction of milk consumed that is contaminated, dimensionless.
B_{oral}	=	Bioavailability; ingestion.

SOIL 6 VEGETABLES 6 HUMANS (INGESTION)

Equation #1

$$C_{veg(soil)} = C_{soil(bulk)} B_{veg}$$

where:

$C_{veg(soil)}$	=	Equilibrium concentration of contaminant in leafy vegetables due to root uptake (wet weight), mg kg^{-1} or pCi kg^{-1};
$C_{soil(bulk)}$	=	Average concentration of contaminant in bulk soil, mg kg^{-1} or pCi kg^{-1};
B_{veg}	=	Concentration ratio for the transfer of contaminant from dry soil to leafy vegetables (wet weight), dimensionless.

Equation #2

$$I_{veg(soil)} = C_{veg(soil)} U_{veg} f_{cv} B_{oral} \quad \text{chemical}$$

$$I_{veg(soil)} = C_{veg(soil)} U_{veg} f_{cv} \quad \text{radionuclide}$$

where:

$I_{veg(soil)}$	=	Daily intake of contaminant due to leafy vegetable ingestion (soil pathway), mg d^{-1} or pCi d^{-1};
$C_{veg(soil)}$	=	Equilibrium concentration of contaminant in leafy vegetables due to root uptake (wet weight), mg kg^{-1} or pCi kg^{-1};
U_{veg}	=	Average daily consumption of vegetables (wet weight), kg d^{-1};
f_{cv}	=	Fraction of vegetables consumed that is contaminated, dimensionless.
B_{oral}	=	Bioavailability; ingestion.

SOIL 6 PASTURE 6 LIVESTOCK/GAME (BEEF) 6 HUMANS (INGESTION)

Equation #1

$$C_{past(soil)} \text{ ' } C_{soil(bulk)}\ B_{past}$$

where:

$C_{past(soil)}$ = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg kg^{-1} or pCi kg^{-1};

$C_{soil(bulk)}$ = Average concentration of contaminant in bulk soil, mg kg^{-1} or pCi kg^{-1};

B_{past} = Concentration ratio for the transfer of contaminant from dry soil to pasture (dry weight), dimensionless.

Equation #2

$$C_{beef(past)} \text{ ' } C_{past(soil)}\ Q_{past(b)}\ F_f\ f_{pb}$$

where:

$C_{beef(past)}$ = Equilibrium concentration of contaminant in beef (soil pathway), mg kg^{-1} or pCi kg^{-1};

$C_{past(soil)}$ = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg kg^{-1} or pCi kg^{-1};

$Q_{past(b)}$ = Daily ingestion of pasture (dry weight) by beef cattle, kg d^{-1};

F_f = Biotransfer factor from cattle intake to meat concentration, (mg kg^{-1})/(mg d^{-1}) or (pCi kg^{-1})/(pCi d^{-1}); and

f_{bp} = Fraction of feed ingested by beef cattle that is pasture, dimensionless.

Equation #3

$$I_{beef(past.)} \text{ ' } C_{beef(past)}\ U_{beef}\ f_{cb}\ B_{oral}$$ chemical

$$I_{beef(past.)} \text{ ' } C_{beef(past)}\ U_{beef}\ f_{cb}$$ radionuclide

where:

$I_{beef(past)}$ = Daily intake of contaminant due to beef ingestion (pasture), mg d^{-1} or pCi d^{-1};

$C_{beef(past)}$ = Equilibrium concentration of contaminant in beef due to pasture, mg kg^{-1} or pCi kg^{-1};

U_{beef} = Average daily consumption of beef, kg d^{-1};

f_{cb} = Fraction of beef consumed that is contaminated, dimensionless.

B_{oral} = Bioavailability; ingestion.

SOIL 6 PASTURE 6 DAIRY CATTLE (MILK) 6 HUMANS (INGESTION)

Equation #1

$$C_{past(soil)} = C_{soil(bulk)}\ B_{past}$$

where:

$C_{past(soil)}$ = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg kg^{-1} or pCi kg^{-1};

$C_{soil(bulk)}$ = Average concentration of contaminant in bulk soil, mg kg^{-1} or pCi kg^{-1};

B_{past} = Concentration ratio for the transfer of contaminant from dry soil to pasture (dry weight), dimensionless.

Equation #2

$$C_{milk(past)} = C_{past(d)}\ Q_{past(d)}\ F_m\ f_{pd}$$

where:

$C_{milk(past)}$ = Equilibrium concentration of contaminant in milk (soil pathway), mg L^{-1} or pCi L^{-1};

$C_{past(soil)}$ = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg kg^{-1} or pCi kg^{-1};

$Q_{past(d)}$ = Daily ingestion of pasture (dry weight) by dairy cattle, kg d^{-1};

F_m = Biotransfer factor from cattle intake to milk concentration (mg L^{-1})/(mg d^{-1}) or (pCi L^{-1})/(pCi d^{-1}); and

f_{pd} = Fraction of feed ingested by dairy cattle that is pasture, dimensionless.

Equation #3

$$I_{milk(past)} = C_{milk(past)} U_{milk} f_{cm} B_{oral} \quad \text{chemical}$$

$$I_{milk(past)} = C_{milk(past)} U_{milk} f_{cm} \quad \text{radionuclide}$$

where:

$I_{milk(past)}$ = Daily intake of contaminant due to milk ingestion (pasture), mg d^{-1} or pCi d^{-1};

$C_{milk(past)}$ = Equilibrium concentration of contaminant in milk due to pasture, mg L^{-1} or pCi L^{-1};

U_{milk} = Average daily consumption of milk, L d^{-1};

f_{cm} = Fraction of milk consumed that is contaminated, dimensionless.

SOIL 6 HUMANS (GROUND EXPOSURE) - RADIONUCLIDES ONLY

$$I_{surf} = C_{soil(surf)} BD f_t f_s Cf_1$$

here:

I_{surf} = Exposure from radionuclides in surface soil, Bq m^{-3};

$C_{soil(surf)}$ = Equilibrium concentration of contaminant in surface soil, pCi kg^{-1};

BD = Soil bulk density, kg m^{-3};

f_t = Fraction of time exposed, dimensionless;

f_s = Indoor/outdoor shielding factor, dimensionless;

Cf_1 = Conversion factor, Bq pCi^{-1}.

APPENDIX K

LEVEL I & II EXPOSURE PARAMETERS FOR THE TASK 6 SCREENING ASSESSMENT

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APPENDIX K: LEVEL I & II EXPOSURE PARAMETERS FOR THE TASK 6 SCREENING ASSESSMENT

The Task 6 screening methodology used two exposure assessments to estimate screening indices. The Level I assessment represents a conservative (upper bound) estimate of the health impacts from uranium releases and is characterized by higher consumption rates of produce raised at the reference location, and by a greater residence time at that location. The Level II assessment is designed to estimate the screening index for an average, more typical individual, and as such uses median produce consumption values, shorter exposure frequencies, a lower fraction of produce raised at the reference location, and the individual is expected to spend more time away from the reference location. Exposure parameters determine the magnitude of exposures and deal with:

- intake of consumables (meat, milk, vegetables, fish),
- incidental intake of soil and incidental ingestion of surface water during recreational activities,
- the fraction of time spent within the contaminated environment,
- physiological measures such as breathing rates,
- livestock breathing rates, pasture consumption, water intake, incidental soil intake, and
- foliar deposition inputs for vegetation, including interception fractions, deposition velocities, and weathering rates.

Two sets of exposure assessment parameters were used to quantify material intake by individuals at the reference locations. The parameter values used for each assessment, and rationale for their selection, are presented in Table K-1.

Table K-1: Level I & II Exposure Parameters For Task 6 Screening

Parameter	Symbol	LEVEL I Value	LEVEL II Value	Adult Value, with Rationale
Exposure frequency, general ($d\ y^{-1}$)	EF	365	350	Professional judgement (assumes that the individual was present year-round at the point of exposure (i.e., no vacation)). The latter value is recommended by the USEPA (Fields and Diamond 1991).
Quantity of air inhaled per day ($m^3\ d^{-1}$)	U_{air}	20	20	Upper bound inhalation rate for housewives, retired employees, unemployed workers, service workers, and household workers (USEPA 1985; cited in Fields and Diamond 1991); this is consistent with the average quantity of air breathed by men and women (23 and 21 $m^3\ d^{-1}$, respectively) working light activity (8 hr d^{-1}), at nonoccupational activity (8 hr d^{-1}), and resting (8 hr d^{-1}) (ICRP 1975).
Fraction of time that person is exposed to contaminated air (unitless)	f_t	0.8	0.4	Professional judgement (Levels I and II assume that the individual was away from his property no more than 5 and 10 hr d^{-1}, respectively).
Fraction of day when individual is exposed, ground exposure (unitless)	$F_{t,\ ext}$	1.0	0.3	The Level I value (1) is based on the assumption that the individual lives on contaminated soil, works outside, and also receives an exposure while indoors. The Level II value (0.3) is based on the assumption that the individual is exposed only 30% of the time ; the value is representative of a person in the area 8 hr/d.
Indoor/Outdoor shielding factor (unitless)	f_s	0.5	0.3	The Level I value (0.5) is an upper-bound for 1-2 story wood frame houses (Roed 1990); consistent with range of 0.05 to 0.65 for wood frame houses (Burson and Profio 1977). 0.3 is upper bound for brick or stone houses(Roed 1990).
Mass loading of particles in ambient air ($mg\ m^{-3}$)	M	0.065	0.065	Arithmetic mean of annual average TSP concentrations in Oak Ridge, 1976-1980 (Boyle et al. 1982).
Enhancement factor (unitless)	F	1	1	Professional judgement (assumes no particle-size enrichment)

Table K-1: Level I & II Exposure Parameters For Task 6 Screening

Parameter	Symbol	LEVEL I Value	LEVEL II Value	Adult Value, with Rationale
Average daily consumption of beef (kg d^{-1})	U_{beef}	0.3	0.1	Based on average total intake of meat by adults of approximately 0.258 k d^{-1} (Rupp 1980). The Level II value is based on an average consumption of beef (0.086 kg d^{-1} (Rupp 1980)).
Fraction of beef consumed that is contaminated (unitless)	f_{cb}	0.8	0.3	Professional judgement (assumes that beef was obtained from several sources, rather than from a single source)
Average daily consumption of milk (L d^{-1})	U_{milk}	1.0	0.3	This value is exceeded by fewer then 2.6% of adults 20-54 years old (Pao and Burk 1975; cited in Rupp 1980). Ninety percent or more are < 0.971 L d^{-1}. Level II is average for male between age 30 and 60 (Rupp 1980)
Fraction of milk consumed that is contaminated (unitless)	f_{cm}	1.0	0.5	Professional judgement (assumes that the maximally exposed individual obtained 100% of his milk from a backyard cow). Level II assumes individual gets one-half of milk from contaminated sources.
Average daily ingestion of soil by adults (kg d^{-1})	U_{soil}	0.0001	0.00005	The Level I value is the reasonable maximum and average exposures for apartment dwellers, typical homeowners, office workers, teachers, professionals (non-contact intensive) reported in Sedman (1989; cited in ATSDR 1992). The Level II is the central tendency for non-contact intensive persons (Calabrese et al 1990; cited in ATSDR 1992).
Fraction of soil ingested by humans that is contaminated	f_{sc}	0.7	0.25	The Level I value (0.7) is based on the assumption that a child lives near a contaminated playground or an adult lives in or near a contaminated area. The Level II value (0.25) is based on the assumption that the individual is exposed to contaminated soil 25% of the time or 6 hr d^{-1}.

Table K-1: Level I & II Exposure Parameters For Task 6 Screening

Parameter	Symbol	LEVEL I Value	LEVEL II Value	Adult Value, with Rationale
Average daily consumption of vegetables (0.5 kg d^{-1} wet weight)	U_{veg}	0.5	0.2	The Level I value is based on average total intake of all fresh produce by adults (including leafy vegetables, deep yellow vegetables, legumes, other vegetables, citrus including tomatoes, other fruit, and potatoes) of approximately 0.48 k d^{-1} in 1955 and 0.44 kg d^{-1} in 1965 (Rupp 1980). The Level II value is the average intake of vegetables for adults reported by Rupp 1980), Fields and Diamond (1991), and ATSDR (1992).
Fraction of vegetables consumed that is contaminated (unitless)	f_{cv}	0.6	0.2	Professional judgement (assumes that vegetables were obtained from several sources, as opposed to from a single source).
Fraction of contaminant remaining on vegetables after washing (unitless)	f_w	0.7	0.2	Consistent with the upper bound of the ranges (IAEA 1992; 1994) for removal of ^{90}Sr, ^{137}Cs, ^{131}I, and ^{106}Ru from spinach by washing and blanching. Level II consistent with midpoint values from same references.
Total Deposition Velocity onto vegetables $(m\ d^{-1})/(kg\ m^{-2})$	$V_{d\text{-}veg}$	385	385	Calculated using a deposition velocity for particulates and a mass interception factor for leafy vegetation. The deposition velocities include both wet and dry deposition and are ratioed based on the percentage of time precipitation occurs. The calculation steps and parameters used to derive this value were presented in Volume II of the Phase I report (ChemRisk 1993)
Total Deposition Velocity onto pasture $(m\ d^{-1})/(kg\ m^{-2})$	$V_{d\text{-}past}$	2570	2570	Used a similar methodology to that used for vegetables to evaluate total deposition onto pasture. Variance is due to differences in biomass yield (ChemRisk 1993)
Incidental consumption of surface water during recreational activities (L h^{-1})	$U_{water(r)}$	0.05	0.05	Rate of incidental ingestion of surface water while swimming (USEPA 1989b).
Fraction contaminated surface water (incidental consumption, dermal contact during recreation) (unitless)	$f_{cw(r)}$	1	1	Professional judgement (assumes that the above incidental water consumption rate applies to contaminated water bodies only).

Table K-1: Level I & II Exposure Parameters For Task 6 Screening

Parameter	Symbol	LEVEL I Value	LEVEL II Value	Adult Value, with Rationale
Exposure time to water during recreation, EFPC (incidental consumption, dermal contact) (h d^{-1})	$ET_{w(IF)}$	0.5	0.5	Professional judgement (assumes limited direct contact time with East Fork Poplar Creek water by an adult, i.e., no more than one-half hour per incident)
Exposure time to surface water during recreational activities, Clinch River (incidental consumption and dermal contact) (h d^{-1})	$ET_{w(CR)}$	4	4	Professional judgement (based on the assumption that exposure time in the Clinch River was higher than in EFPC due to the larger size of the waterway and improved water quality, and the lack of air conditioning during the 1940s)
Frequency of exposure to water during recreation, EFPC (incidental consumption, dermal contact) (d y^{-1})	$EF\text{-}A_{w(EF)}$	4	4	Professional judgement
Exposure frequency to surface water during recreations, Clinch River (incidental consumption, dermal contact) (d y^{-1})	$EF\text{-}A_{w(CR)}$	8	8	Professional judgement
Average daily consumption of fish, EFPC (kg d^{-1})	$U_{fish(EF)}$	0.004	0.004	Consumption of fish from EFPC; based on ingestion rates from 1.2 to 4.1 g d^{-1} for recreational anglers in small ponds or streams (USEPA 1994). Activity is likely to be low due to limited access, the nature of the Creek, and the availability of higher quality fisheries nearby, but that an angler might have used the Creek on an infrequent basis, particularly if they lived nearby.
Average daily consumption of fish, Clinch River/Poplar Creek (kg d^{-1})	$U_{fish(CR)}$	0.01	0.01	Consumption of fish from Clinch River/Poplar Creek associated with recreational angling based on fish ingestion rates ranging from 8 to 10 g d^{-1} (Ebert 1996). Based on estimated angler activity for Tennessee anglers in general from the 1991 USFWS survey (USDOI 1993) and consumption rates of fish from Tennessee Rivers from Todd (1990).
Fraction of fish consumed that is contaminated (unitless)	f_{cf}	1	1	The above fish consumption rates are specific to consumption of fish caught from the respective water body

Table K-1: Level I & II Exposure Parameters For Task 6 Screening

Parameter	Symbol	LEVEL I Value	LEVEL II Value	Adult Value, with Rationale
Daily inhalation rate of beef cattle (m^3 d^{-1})	$Q_{air(b)}$	122	122	(McKone 1988).
Daily inhalation rate of dairy cattle (m^3 d^{-1})	$Q_{air(d)}$	150	150	(McKone 1988).
Daily ingestion of feed by beef cattle(kg d^{-1}) (dry weight)	$Q_{feed(b)}$	10	7.2	Upper bound of range for dry matter intake of beef cattle (IAEA 1994). Level II is the expected value (IAEA 1994)
Fraction of feed ingested by beef cattle that is from contaminated pasture (unitless)	f_{pb}	1.0	0.4	Professional judgement (assumes that the cow's diet consisted solely of pasture and/or hay grown on the same land as the pasture)
Daily ingestion of feed by dairy cattle (kg d^{-1})	$Q_{feed(d)}$	16	9.1	Per Husted-Anderson (1941), dairy cattle ate 11 -17.8 kg d^{-1} dry matter in managed feeding. It was assumed that the milk was obtained from backyard cattle and that "these animals typically forage on semi-wild vegetation and not much effort is made to improve the quality of pasture unless other grazing stock require it" (Koranda 1965). Given the economic conditions in the 1940s to 1960s, improvements to pasture were unlikely. Consistent with the upper bound reported by Koranda (1965) for cattle with unmanaged feeding regime. Level II is the mean estimate (Koranda 1965).
Fraction of feed ingested by dairy cattle that is from contaminated pasture (unitless)	f_{pd}	0.75	0.3	Professional judgement (assumes the diet of dairy cattle was partially supplemented, but most was pasture or hay grown on the same land as pasture). Level II assumes the cow receives only 30 % of its food from contaminated pasture.
Weathering rate constant for vegetation (vegetables and pasture) (d^{-1})	k_w	0.05	0.05	Based on environmental half-time of 14 d, corresponding to a value assumed representative of all radionuclides and plant types (Miller and Hoffman 1983)
Growth period or exposure period for vegetables (d)	T_g	60	60	Crop exposure period for produce (NCRP 1985)
Growth period or exposure period for pasture (d)	T_g	30	30	Crop exposure period for pasture (NCRP 1985)

Table K-1: Level I & II Exposure Parameters For Task 6 Screening

Parameter	Symbol	LEVEL I Value	LEVEL II Value	Adult Value, with Rationale
Daily intake of water by beef cattle (L d^{-1})	$Q_{water(b)}$	50	44	Upper bound of range reported for beef cattle (range 38 - 50 L d^{-1}; McKone 1988). Median value is used for Level II.
Daily intake of water by dairy cattle (L d^{-1})	$Q_{water(d)}$	60	48	Upper bound of range for dairy cattle (range 38 - 60 L d^{-1}; McKone 1988). Median value is used for Level II.
Fraction of water consumed by cattle that is contaminated (unitless)	$f_{cw(c)}$	1	1	Professional judgement (based on the assumption that 100% of water was from the contaminated source)
Daily ingestion rate of soil by beef and dairy cattle (kg d^{-1})	$Q_{soil(b)}$	0.5	0.25	Upper bound of soil ingestion rate for beef and dairy cattle [range 0.1 - 0.72 kg d^{-1}; arithmetic mean 0.39 kg d^{-1} (beef) and 0.41 kg d^{-1} (dairy)] (McKone 1988). Level II is the geometric mean (Gilbert et al. 1995).
Fraction of soil ingested by cattle that is contaminated (unitless)	$f_{cs(c)}$	1	1	Professional judgement (assumes that the cow grazed 100% of the time in a contaminated area)

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APPENDIX L

OAK RIDGE DOSE RECONSTRUCTION (TASK 6)
HISTORICAL INVESTIGATION INTERVIEWS
FOR THE URANIUM INVESTIGATION

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PERSONAL COMMUNICATIONS

No.	Name	Plant(s)	Expertise	Years at ORR	
1	Jack Bailey	K-25	Health Physics/Effluent Monitoring	41	(1944-1985)
2	Bob Bowers	Y-12	Health Physics/Effluent Monitoring	30	(1967-present)
3	Herman Butler	Y-12	Production/Process Control	43	(1951-1994)
4	Todd Butz	Y-12	Environmental Monitoring	20	(1977-present)
5	Joel Carter	K-25, X-10, and Y-12	Production/Environmental Monitoring	53	(1944-present)
6	John Chiang	K-25 and Y-12	Production/Process Monitoring	21	(1976-present)
7	Joe Dykstra	K-25	Production/Process Monitoring	46	(1944-1990)
8	Henry Fellers	K-25 and Y-12	Stack/Environmental Monitoring	26	(1971-present)
9	William Franke	Y-12	Waste Processing	31	(1944-1975)
10	John Googin	Y-12	Process Development/Effluents	51	(1943-1994)
11	Boyd Gose	Y-12	Health Physics/Monitoring	28	(1969-present)
12	William Griffith	Y-12	Process Engineer/Electromagnetic Enrichment	47	(1950-present)
13	Clarence Hill	Y-12	Environmental Monitoring	13	(1984-present)
14	BiLL Hopwood	Y-12	Accountability/Material Control	26	(1971-present)
15	Jerry Hunt	Y-12	Health Physics	26	(1971-present)
6	John Kreykes	Y-12	Enriched Uranium Production	13	(1984-present)
17	Gus Legeay	K-25	Production/Historian	44	(1953-present)
18	Lisa Loden	Y-12	Engineering/Effluent Monitoring	17	(1980-present)
19	Lowell McCawley	K-25 and Y-12	Process Control/Environmental Surveillance	46	(1950-1996)
20	John Napier	Y-12	Engineer/Waste Management/Process Control	34	(1956-1990)
21	James Rogers	K-25	Engineer/Accountability/Effluents	28	(1969-present)
22	Dan Rowan	Y-12	Health Physics/Contamination Monitoring	28	(1969-present)
23	Bob Rutherford	Y-12	Health Physics/Contamination Monitoring	44	(1950-1994)
24	Merwyn Sanders	Y-12	Health Physics/Contamination Monitoring	44	(1945-1989)
25	William Schappel	K-25 and Y-12	Engineer/Effluent Monitoring	47	(1950-present)
26	Neil Schultz	K-25 and Y-12	Health Physics/Radiological Monitoring	41	(1944-1985)
27	William Sharp	X-10	Metallurgical Data/Environmental Monitoring	25	(1972-present)
28	Iris Shelton	Y-12	Stack Monitoring	19	(1978-present)
29	David Smith	Y-12	Production (Enriched and Depleted Uranium)	46	(1944-1990)
30	David Stoddard	K-25	Industrial Hygiene/Monitoring	36	(1944-1980)
31	John Strohecher	Y-12	Production Engineers/S-3 and New Hope Pond	51	(1944-1975)
32	Steve Trotter	K-25 and Y-12	Health Physics/Environmental Monitoring	19	(1978-present)
33	William Tucker	Y-12	Laboratory Analyses/Effluent Sampling	33	(1964-present)
34	Charles West	Y-12	Health Physics/Radiological Monitoring	42	(1944-1985)
35	Frank Gifford	ORR	Atmospheric Dispersion/Meteorological Survey	31	(1950-1980)

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APPENDIX M

EVALUATION OF URANIUM CHEMICAL TOXICITY

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1.0 INTRODUCTION TO URANIUM CHEMICAL TOXICITY

This appendix describes the methods and data reviewed by Task 6 for assessing the potential chemical toxicity effects from uptake of uranium via either inhalation or ingestion.

In brief, this appendix includes descriptions of the following:

- a brief summary of relevant literature on chemical effects; and
- recommendations for further assessment of the heavy metal (chemical) toxicity of uranium intakes.

The format of this appendix is an overview of the chemical toxicity of uranium and recommended risk factors.

2.0 HEALTH EFFECTS FOR URANIUM

2.1 Radiation Effects

Uranium isotopes emit low energy alpha particles and, to a lesser extent, gamma rays. Exposure to low levels of radiation emitted by uranium will not cause radiation sickness or other acute health effects generally associated with doses greater than 50 rads. However, there is some evidence to suggest that exposure to any level of radiation can increase the risks of cancer. However, the main topic of this appendix is a review of the chemical effects (seen mostly in kidneys) as a result of exposure to uranium.

2.2 Chemical Effects

The chemical form of the uranium compound is very important when assessing the exposure pathways for uranium. The higher the solubility of the uranium, the more it can be absorbed into the body. Insoluble compounds are absorbed to a much lower extent, however, inhaled uranium can accumulate in the lung. For evaluating chemical toxicity from both inhalation and ingestion exposure pathways, soluble compounds of uranium (Type F or Class D) were used in the Task 6 screening, since they represents the "worst-case" for a chemical toxicity assessment for uranium.

2.2.1 Nephrotoxicity

A number of studies in the literature indicate that the kidney is the major organ for damage from exposure to uranium. However, there is still considerable debate surrounding the appearance of biochemical substances in the urine, such as protein, alkaline phosphatase, or beta-2-microglobulin, as indicators of renal damage. These effects are generally reversible, and disappear when the stimulus (uranium intake) is removed. Therefore, for the purpose of this report, damage to the proximal tubules in the kidney is considered to be the major toxic effect of exposure to uranium.

2.2.2 Biokinetics

Once uranium has entered the body via ingestion, it can be absorbed from the gastrointestinal tract. The amount absorbed is generally determined by the solubility of the compound. For soluble compounds, the GI absorption fraction for humans ranges between 0.7% and 3%. A value of 2% has been adopted by the most recent report of the International Commission on Radiological Protection (ICRP), and is used for modeling purposes in the Task 6 assessment. This value was lowered from a previous value of 5%.

Uranium in the blood stream exists as two different complexes: a uranyl bicarbonate complex and a uranyl transferring complex. The uranyl bicarbonate complex can be easily dissociated once it enters the kidney. The uranyl transferring complex is more tightly bound, and thus exists for a longer period of time in the body. These two complexes exist in equilibrium, which results in all the uranium being eventually excreted from the body some time after ongoing exposure is eliminated.

Several biokinetic models can be used to describe the behaviour of the two compounds of uranium, as well as the tissues where uranium is deposited. For the Task 6 screening assessment, inhalation and ingestion were evaluated separately. For ingestion, the LUDEP 2.0 model was used to calculate kidney burdens (NRPB 1996). This model uses the ICRP 30 biokinetics and parameters for kidneys and skeleton (ICRP 1977). For inhalation, the LUDEP 2.0 model employs the latest lung model from ICRP 66 in conjunction with the biokinetic models and parameters from ICRP 30 (ICRP 1979). These models were used to calculate kidney burdens based on various intake values for uranium.

Once the kidney burdens are calculated using the models, they are compared to concentrations that are not expected to show any renal damage (effects threshold). There are only two studies (Russel et al. 1996; Zhao and Zhao 1990) that report reliable data for kidney threshold values in humans. These studies are included in Table M-1 of this appendix. From Table M-1, it can be seen that effects threshold values range from 0.3 - 2.6 $\mu g\ g^{-1}$ in kidney tissue. There is an order of magnitude difference between the two human studies, however, this can be accounted for by applying a safety factor of 10 to the latter value. The majority of the other studies in the table were carried out using animal subjects (mainly rats and dogs). Rats were found to be less sensitive than dogs or humans to exposure to uranium. The other values reported in the table were derived from evaluating the data of Morrow et al. (1982) and then assuming a value. In general, studies listed in the table involved much higher concentrations of uranium than would be expected in a chronic human exposure scenario. Therefore, a threshold toxicity value of 1 $\mu g\ g^{-1}$ kidney was chosen for the Task 6 screening assessment, since it was between the range of values reported for humans and was supported by the scientific literature (Wrenn et al. 1985; and Kocher 1989).

Table M-1: Summary of Kidney Threshold Values

Threshold Value ($\mu g\ g^{-1}$)	NOAEL or LOAEL	Measure-ment Technique	Type of Exposure	Subjects (number)	Comment	Safety Factor to Apply	Reference
0.3	NOAEL	alpha spec.	Low level occupat. (chronic)	Humans (7)	autopsies		Russel et al (1996)
2.6	NOAEL	not given	Acute	Humans (3)	Urinary output and ICRP calculation	10	Zhao and Zhao (1990)
3	LOAEL	N/A	Acute	Animals	Lit. Review	10	Leggett (1989)
2-3	NOAEL	Fluorimet.	Acute	Rats			Voegtlin and Hodge (1953)
2-6	LOAEL	not given	Acute	Humans (8)	based on body burden calculation; humans were dying		Bernard (1958)
0.1 - 0.4	LOAEL	Fluorimet.	Chronic	Dogs	effect is "mild renal injury"		Hodge (1953) Stokinger (1953)
0.3	LOAEL	Liquid Scintillat. of alpha particles and gamma counting	Acute	Dogs (5)	comments on the fact that dogs are more susceptible than rodents		Morrow et al. (1982)
1.0	LOAEL	N/A	Acute	N/A	based on Morrow and "assumed" a value	50	Wrenn et al. (1985)
1.0	LOAEL	N/A	Assumed Chronic	N/A	based on Wrenn	10	Kocher (1989)

2.3 Adequacy of Database

There are a number of areas where more data (i.e., research) are needed to reduce uncertainties in the human health assessment of uranium.

As discussed in Section 2.2.1, there are several biochemical markers used in the exposure assessment for uranium. For example, beta-2-microglobulin levels are suggested to be indicative of uranium exposure, however, no real correlation has been established between the presence of beta-2-microglobulin in the urine and uranium exposure levels (Moss et al. 1983). The presence of many of these biochemical markers are considered to be reversible effects, not indicative of any permanent renal damage. Therefore, the development of a correlation between the presence of these biochemical markers and permanent damage to kidney tubules would provide a relatively quick method for establishing kidney threshold values.

There are very few studies that have examined postmortem tissue analysis uranium exposure cases for determination of kidney burdens or for estimation of toxic effects threshold values. These data would be extremely useful in reducing the current uncertainties surrounding these values.

There is also a need for more data surrounding effects of chronic exposures to uranium. The data at present focus on acute (high level-one time) exposures that are difficult to extrapolate to the low level-long time exposure scenario. These results would be most helpful in the validation of biokinetic models used to describe effects of chronic exposures to uranium, since the model predictions could be compared with data sets that are independent of the data used to generate the model.

3.0 REGULATIONS AND ADVISORIES

International and North American regulations and guidelines pertinent to human exposure to uranium are summarized in Table M-2. Recommendations for radiation protection for people in the general population as a result of exposure to radiation and radioactive materials in the environment are found in the ICRP 60 document as well as the Code of Federal Regulations dealing with the U.S Nuclear Regulatory Commission (NRC). As can be seen, the two guidelines agree on the exposure limit of 1 mSv y^{-1} for members in the general public, however, there is disagreement with the value for occupationally exposed workers. The ICRP has revised their previous recommendations down to a value of 20 mSv y^{-1}, whereas the NRC have maintained the value of 50 mSv y^{-1}. The NRC also has guidelines for effluent concentrations for both air and water (μCi ml^{-1}). We have proposed the use of Type S characteristics for compounds for assessing chemical toxicity in this report as they represent the most conservative values of risk.

Table M-2: Regulations and Guidelines For Uranium

Agency	Description	Value	Reference
International Guidelines			
ICRP	Occupational - whole body exposure	20 mSv yr^{-1} averaged over 5 y	ICRP 1991
	Individual members of public	1 mSv y^{-1}	
United States			
NRC	Occupationally whole body exposure	50 mSv y^{-1}	USNRC 1991, 10 CFR 20
	Individual members of public	1 mSv y^{-1}	
	Air concentration (µCi ml^{-1}) ^{238}U F M S ^{235}U F M S ^{234}U F M S	 $3x10^{-12}$ $1x10^{-12}$ $5x10^{-14}$ $3x10^{-12}$ $1x10^{-12}$ $6x10^{-14}$ $3x10^{-12}$ $1x10^{-12}$ $6x10^{-14}$	USNRC 1991, 10 CFR 20
	Water concentration (µCi/ml) ^{234}U, ^{235}U, ^{238}U	$3x10^{-7}$	USNRC 1991, 10 CFR 20
EPA	RfD for chronic exposure to soluble uranium salts	0.003 mg kg^{-1} d^{-1}	EPA 1989c
Drinking Water Guidelines			
Canadian			
Health Canada	Maximum Acceptable Concentration	100 µg L^{-1}	Health & Welfare Canada 1989
International			
WHO		NAD	WHO 1993
United States			
EPA		NAD	IRIS 1995

Note: NAD - no adequate data to permit recommendation of a health based guideline value.

There are currently no EPA or WHO drinking water standards for uranium. There have been a number of proposed guidelines ranging from 3 µg L^{-1} (Cothern et al. 1983) to 100 µg L^{-1} (Wrenn et al. 1985). However, these agencies feel that the data base is inadequate, and they are not prepared to propose guidelines at this time. In 1989, the EPA proposed an RfD of 0.003 mg kg^{-1} d^{-1} for chronic exposure to soluble uranium salts based on renal effects in rabbits (EPA 1989c). In 1991, the EPA proposed drinking water standards for radionuclides, including uranium. The proposed "maximum contaminant level" for uranium was 20 µg L^{-1}. However, these proposals resulted in significant debate and comment, and to our knowledge final standards have not been established.

The Canadian drinking water guideline is 100 µg L^{-1}; this is based on an RfD of 0.003 mg kg^{-1} d^{-1}. New Health Canada guidelines to be released in the near future retain the value at 100 µg L^{-1}. However, there exist controversies over this value, since transient biochemical effects have been observed at lower levels (Myerhoff 1996).

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Screening-Level Evaluation of Additional Potential Materials of Concern
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